NPOESS/NPP VIIRS Ocean Measurements: Sea-Surface Temperature

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Overview

- VIIRS requirements.
- Sea-surface temperature – skin and bulk.
- VIIRS SST validation.
- Physical behavior of the skin layer.
- Lessons learned from MODIS.

VIIRS Documents

VIIRS : Visible/Infrared Imager/Radiometer Suite

http://npoesslib.ipo.noaa.gov/ElectLib.htm

VIIRS requirements

- VIIRS will provide valid radiometric earth scene data shall be collected and reported over a ground swath subtending not less than ±55.84^{o} cross track at the satellite location, measured with respect to the nadir direction, in any spectral band needed to meet a threshold requirement for any of the following EDRs:
  - Imagery
  - Sea Surface Temperature
  - …………

VIIRS SST Requirements

- 3.2.1.1.1.2 Sea Surface Temperature (SST)
- Sea surface temperature (SST) is defined as the skin temperature of the ocean surface water. The measured radiances should enable the derivation of both skin and surface layer (1 meter depth) sea surface temperature to the specifications listed below, though an EDR algorithm is only required for skin temperature. The requirements below apply only under clear conditions.
- This EDR must be generated as a dual product at two spatial scales, one meeting the moderate HCS requirements and the other meeting the fine HCS requirements.
- Units: K

Para. No.		Thresholds	Objectives
	a. Horizontal Cell Size		
V40.2.4-1	1. Moderate, at nadir	3 km	1 km
V40.2.4-2	2. Moderate, worst case	4 km	(TBD)
V40.2.4-3	3. Fine, at nadir	1 km	0.25 km
V40.2.4-4	4. Fine, worst case	1.3 km	(TBD)
V40.2.4-5	b. Horizontal Reporting Interval	(TBD)	(TBD)
V40.2.4-17	c. Horizontal Coverage	Oceans	Oceans
V40.2.4-6	Deleted		
V40.2.4-7	Deleted		
V40.2.4-8	d. Measurement Range	271 K - 313 K	271 K - 313 K
V40.2.4-9	e. Measurement Uncertainty (TBR)	0.5 K (TBR)	0.35 K/0.1 K*
V40.2.4-10	f. Measurement Accuracy	0.2 K	0.1 K
V40.2.4-11	g. Measurement Precision	(TBD)	0.1 K
	h. Mapping Uncertainty		
V40.2.4-12	1. Moderate, at nadir	1 km	0.5 km
V40.2.4-13	2. Moderate, worst case	3 km	(TBD)
V40.2.4-14	3. Fine, at nadir	1 km	0.1 km
V40.2.4-15	4. Fine, worst case	3 km	(TBD)
	i. Maximum Local Average Revisit Time	6 hrs	3 hrs
	j. Maximum Local Refresh	(TBD)	(TBD)
V40.2.4-16	k. Minimum Swath Width (All other EDR thresholds met)	1700 km (TBR)	(TBD)

From: VISIBLE/INFRARED IMAGER/RADIOMETER SUITE (VIIRS) Sensor Requirements Document (SRD)

VIIRS SST Requirements

- 3.2.1.1.1.2 Sea Surface Temperature (SST)
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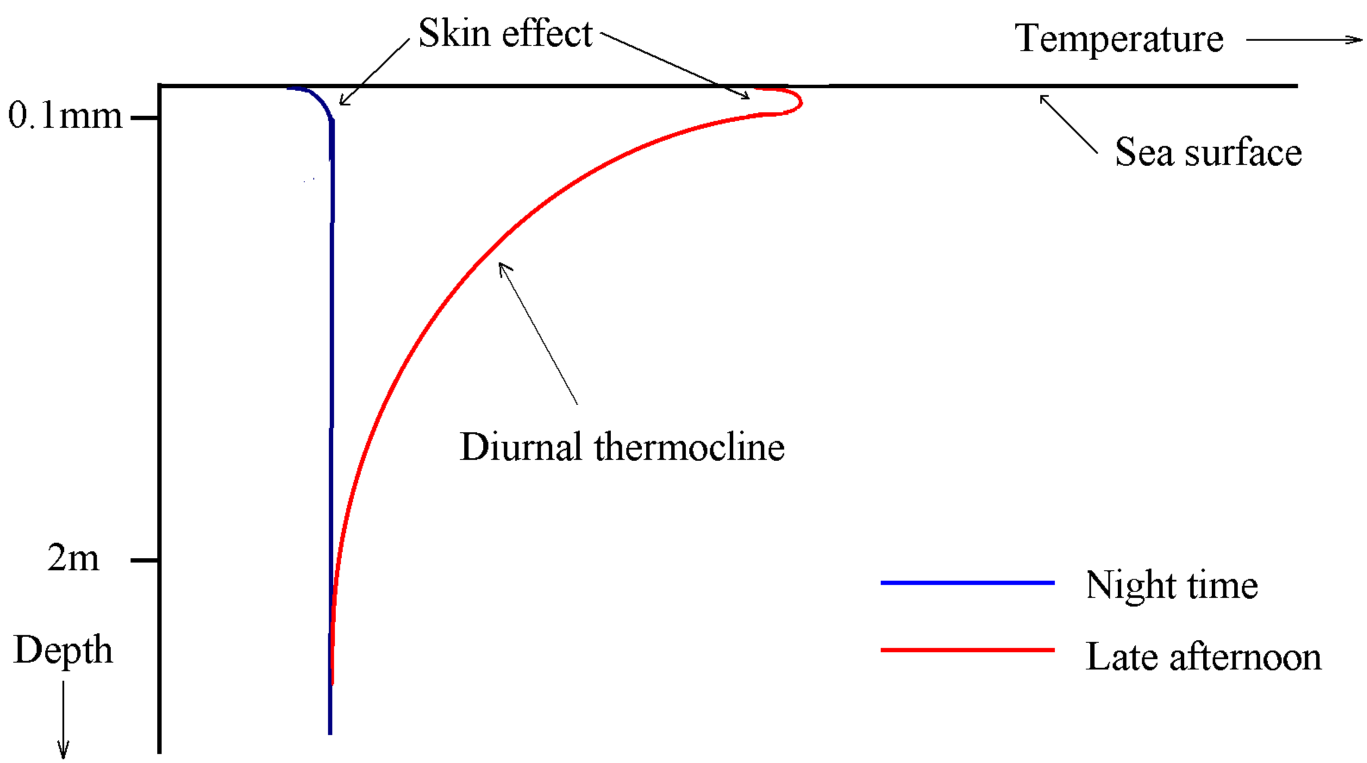
V40.2.4-4	4. Fine, worst case	1.3 km	(TBD)
V40.2.4-5	b. Horizontal Reporting Interval	(TBD)	(TBD)
V40.2.4-17	c. Horizontal Coverage	Oceans	Oceans
V40.2.4-6	Deleted		
V40.2.4-7	Deleted		
V40.2.4-8	d. Measurement Range	271 K - 313 K	271 K - 313 K
V40.2.4-9	e. Measurement Uncertainty (TBR)	0.5 K (TBR)	0.35 K/0.1 K*
V40.2.4-10	f. Measurement Accuracy	0.2 K	0.1 K
V40.2.4-11	g. Measurement Precision	(TBD)	0.1 K
	h. Mapping Uncertainty		
V40.2.4-12	1. Moderate, at nadir	1 km	0.5 km
V40.2.4-13	2. Moderate, worst case	3 km	(TBD)
V40.2.4-14	3. Fine, at nadir	1 km	0.1 km
V40.2.4-15	4. Fine, worst case	3 km	(TBD)
	i. Maximum Local Average Revisit Time	6 hrs	3 hrs
	j. Maximum Local Refresh	(TBD)	(TBD)
V40.2.4-16	k. Minimum Swath Width (All other EDR thresholds met)	1700 km (TBR)	(TBD)

From: VISIBLE/INFRARED IMAGER/RADIOMETER SUITE (VIIRS) Sensor Requirements Document (SRD)

Near surface temperature gradients – ideal, conceptual situation

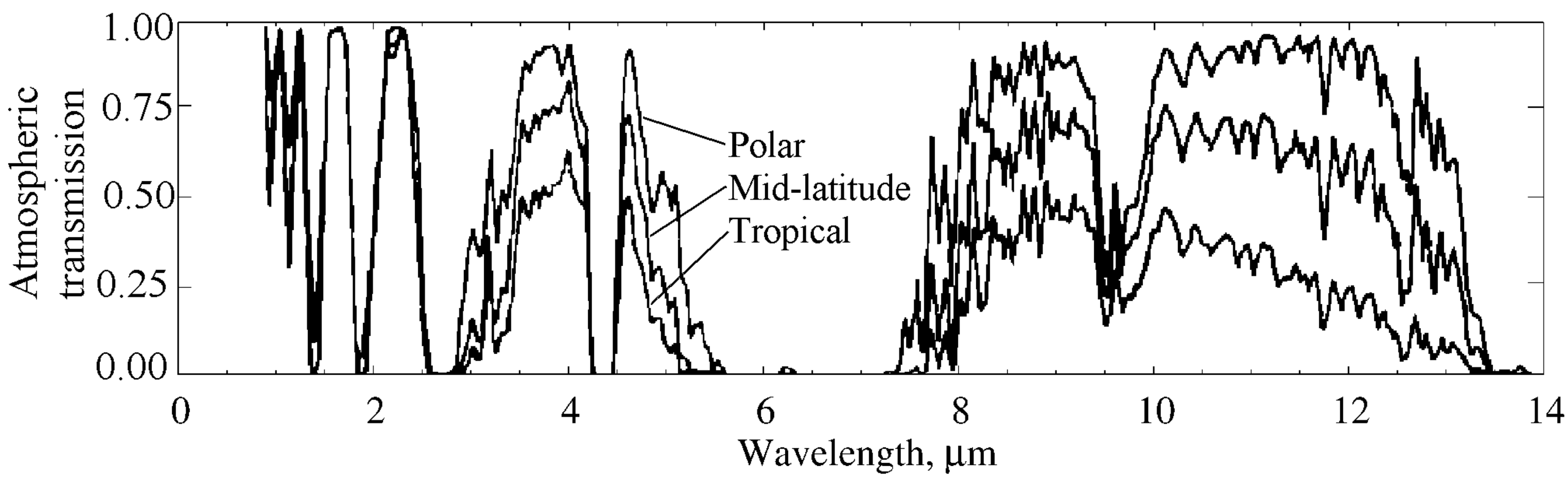


VIIRS SST Requirements

* The incremental value of approaching the 0.35 K objective is greater than the incremental value of surpassing 0.35 K and approaching the 0.1 K objective. Also, the 0.35 K measurement uncertainty objective applies at nadir for the fine product nadir HCS and at any swath location for an HCS that intercepts the same in-track and cross-track angles measured from the satellite location, as the nadir HCS. The fact that this requirement is expressed in terms of an HCS that grows geometrically across the swath does not imply that a varying HCS is required or desired in the reported product at either the fine or moderate scales.

Atmospheric transmission in the infrared

- SST measurements made where atmosphere relatively transmissive.
- Multi-spectral measurements support correction for atmospheric effect.



VIIRS SST algorithms

- **Daytime algorithms:**

  Dual split window (10.8, 12, 3.7, 4.0 µm bands) algorithm: (new)

$$SST = a_0 + a_1T_{11} + a_2T_{12} + a_3(\sec(z)-1) + a_4T_{3.7} + a_5T_{4.0} + a_6T_{3.7}\cos(zs) + a_7T_{4.0}\cos(zs) + a_8(T_{11}-T_{12})^2 \quad (12)$$

  Split window (10.8 + 12 µm bands) nonlinear: (Modified from AVHRR operational, May *et al.*, 1998)

$$SST = a_0 + a_1T_{11} + a_2(T_{11}-T_{12}) + a_3(\sec(z)-1) + a_4(T_{11}-T_{12})^2 \quad (13)$$

- **Nighttime algorithms:**

  Dual split window (10.8, 12, 3.7, 4.0 µm bands) algorithm: (new)

$$SST = a_0 + a_1T_{11} + a_2T_{12} + a_3(\sec(z)-1) + a_4T_{3.7} + a_5T_{4.0} + a_6T_{3.7}^{\ 2} + a_7T_{4.0}^{\ 2} + a_8(T_{11}-T_{12})^2 \quad (14)$$

The VIIRS baseline algorithm uses equation 12 for daytime retrieval and equation 14 for nighttime retrieval (dual split window algorithm). Equation 13 (split window algorithm) is used as the VIIRS fallback algorithm during sun glint conditions. As discussed in version four of this ATBD, higher order polynomial terms and neural networks do not improve the results. Therefore, only second order polynomial terms are used in the VIIRS algorithm. In order to improve uncertainty and accuracy, the SST field is stratified into a few groups, and regression equations are derived for each group. It is necessary to continue validation studies to insure that the quadratic term is well-behaved in all conditions.

What is SST? – the skin *vs*. bulk debate

The optical depth of sea water at infrared wavelengths is < 1mm. The **source of the infrared signal** in the atmospheric windows is the **skin layer** of the ocean, which is generally cooler than the subsurface layer because of heat flow from the ocean to the atmosphere.

The **second** definition of VIIRS **SST** is the temperature measured at a **depth of a meter,** i.e. comparable to that measured by a contact thermometer; the so-called bulk temperature.

At the levels of VIIRS SST accuracy, skin and bulk temperatures are not the same.

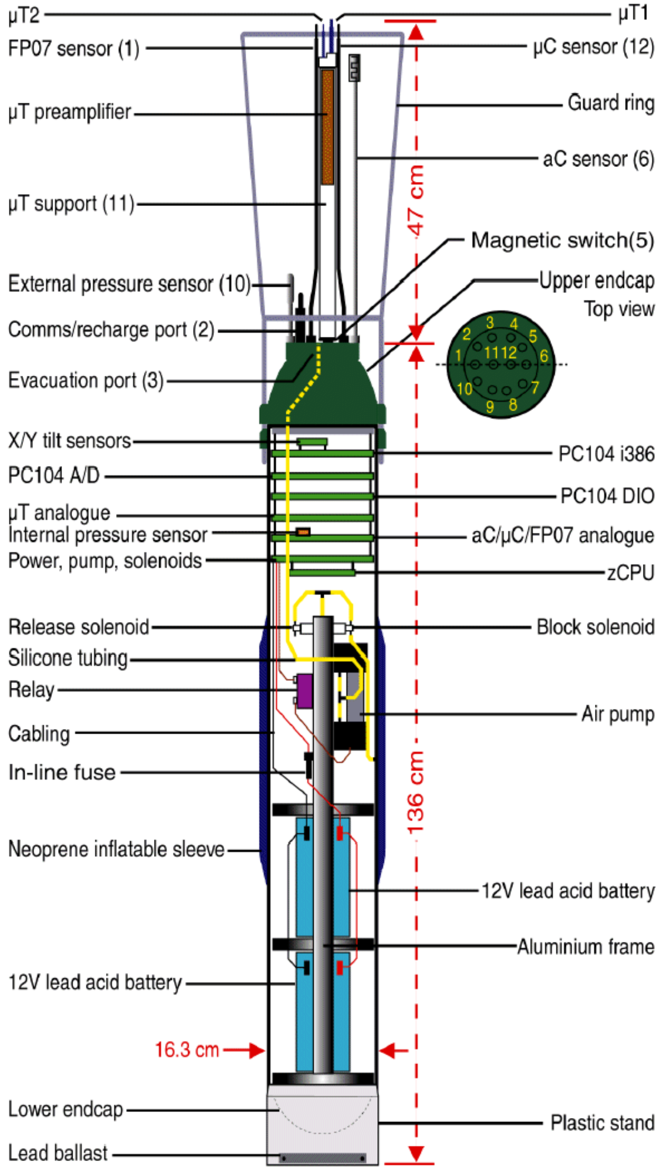
Combined effect of skin and diurnal thermocline effects

• Skin effect responds quickly to changing surface fluxes on time scales of seconds; vertical scale <1mm.

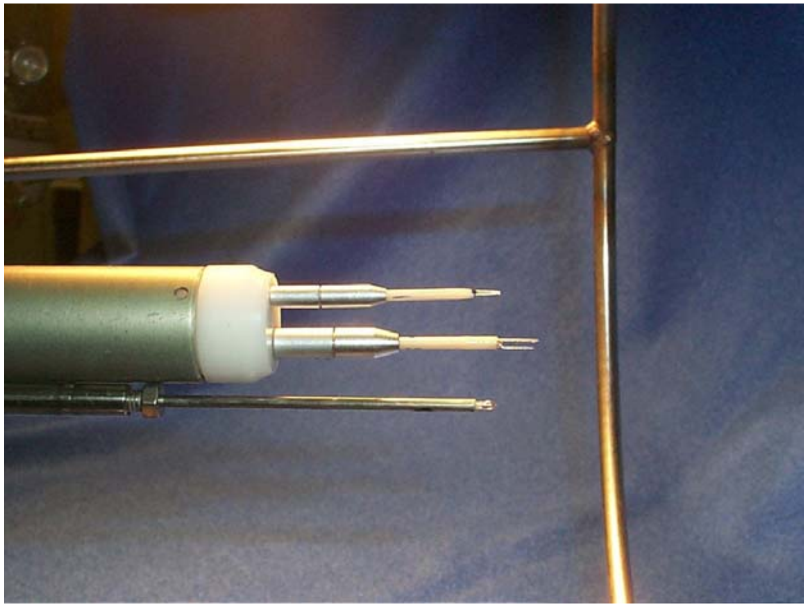
• Diurnal thermocline, a.k.a a surface warm layer, integrates fluxes, and responds to changing surface fluxes on time scales of minutes to hours; vertical scale of several m.

• Signs of effects are usually opposite.

SkinDeEP

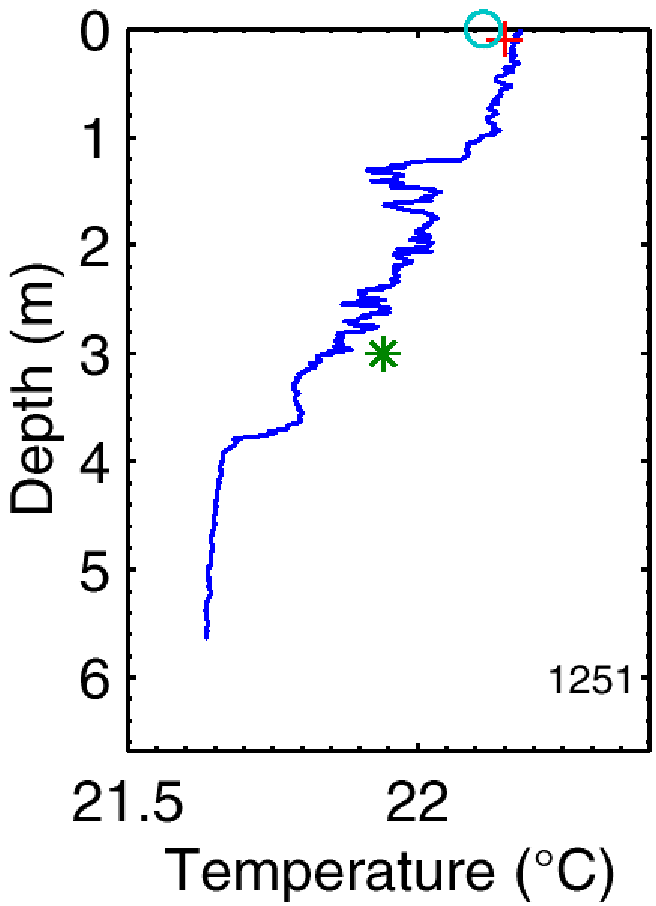


Skin Depth Experimental Profiler



Microstructure probes

Near surface temperature gradients – reality



Profile measured at 12:51 local time on

4 October 1999. Off Baja California,

R/V *Melville* MOCE-5 cruise.

Blue line = SkinDeEP* profile

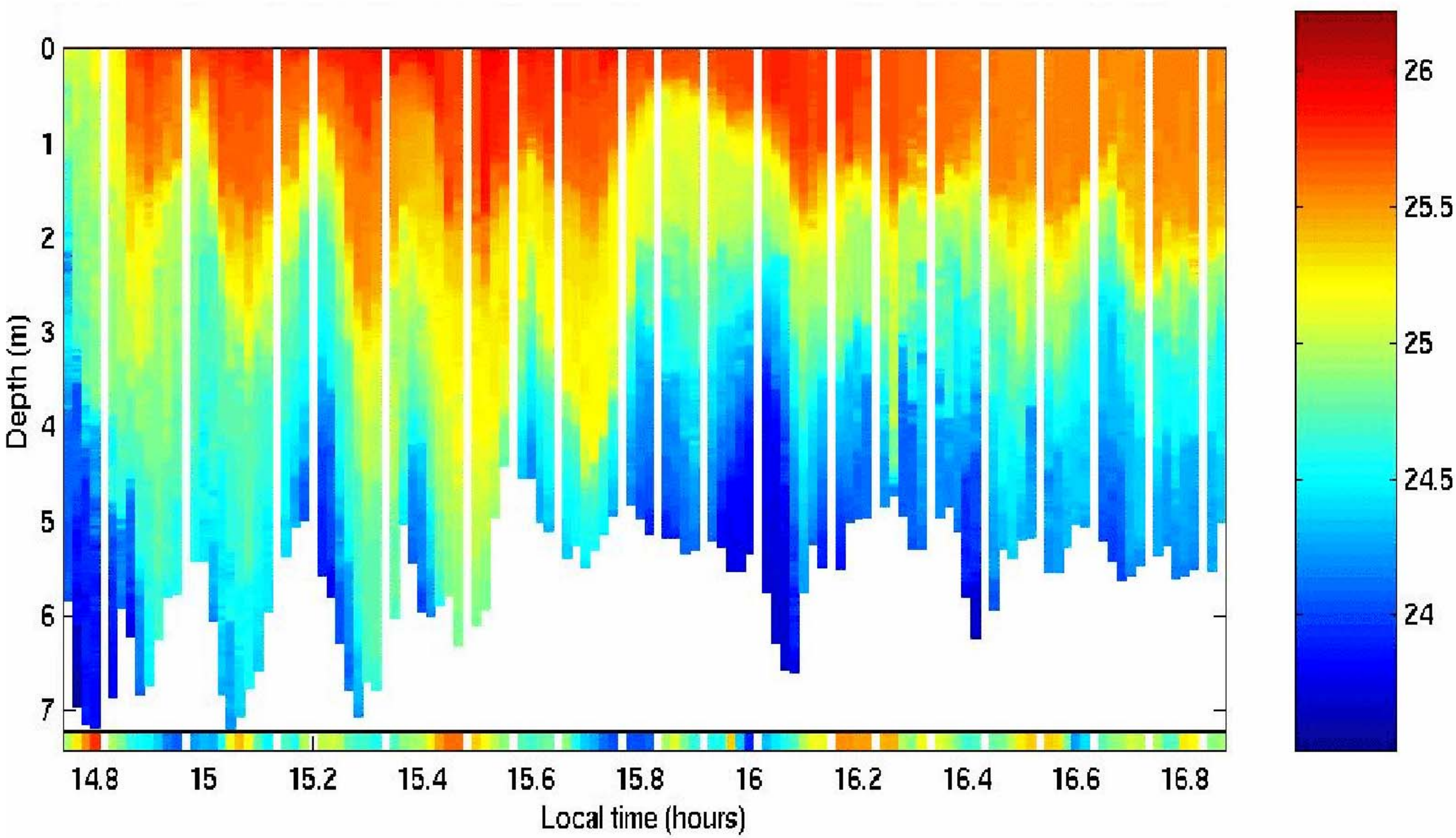
Blue circle = M-AERI skin temp.

Red cross = Float bulk SST at ~0.05m

Green star = Ship thermosalinograph at ~3m

From Ward, B. and P. J. Minnett, 2001. An autonomous profiler for near surface temperature measurements. *Gas Transfer at Water Surfaces.* M. A. Donelan, W.M. Drennan, E.S. Saltzmann and R. Wanninkhof (Eds.) *American Geophysical Union Monograph 127.* 167 - 172.

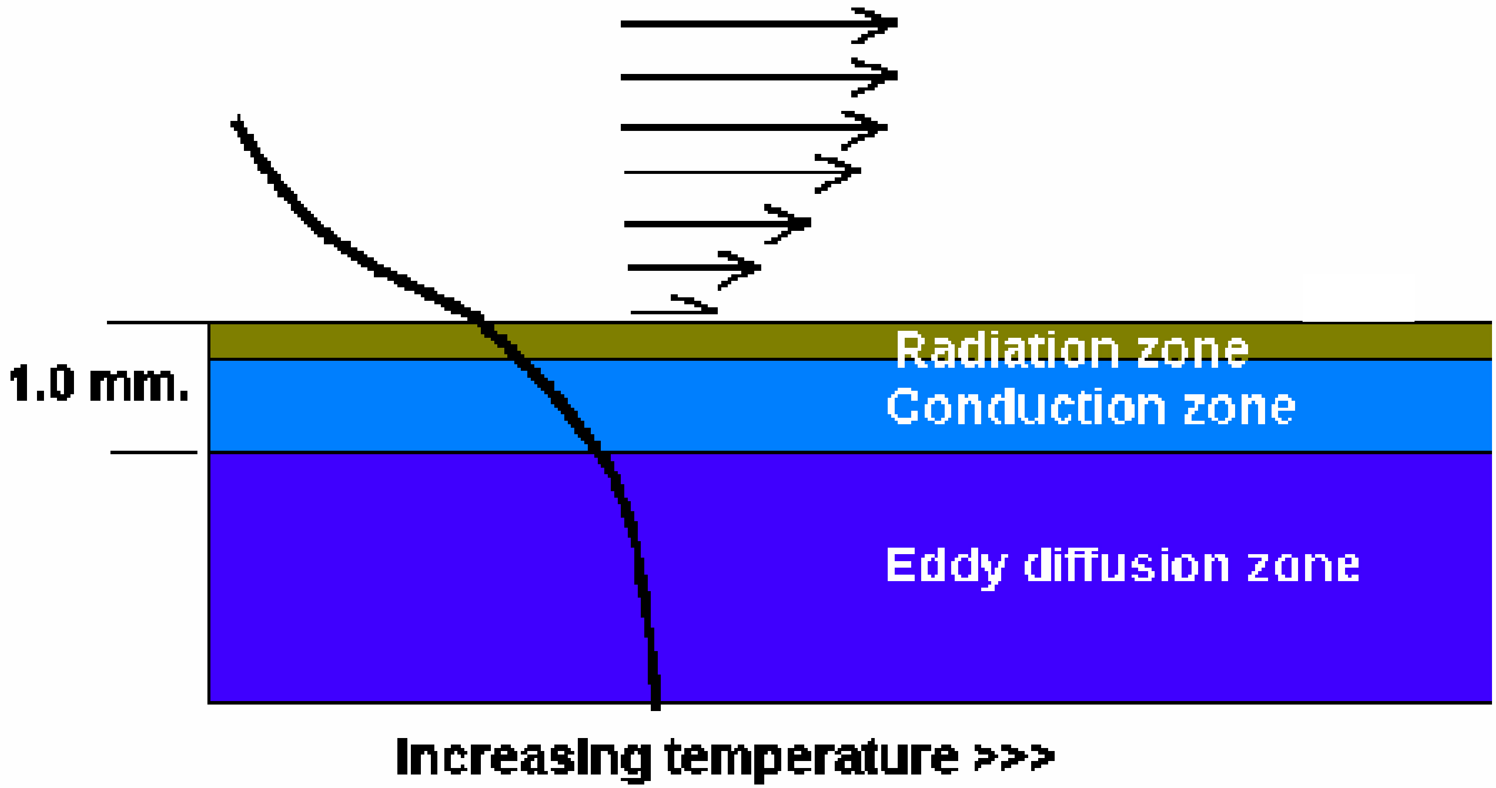
Time evolution of near-surface thermal gradients



SkinDeEP profiles on 12 October 1999. Off Baja California, R/V *Melville*.

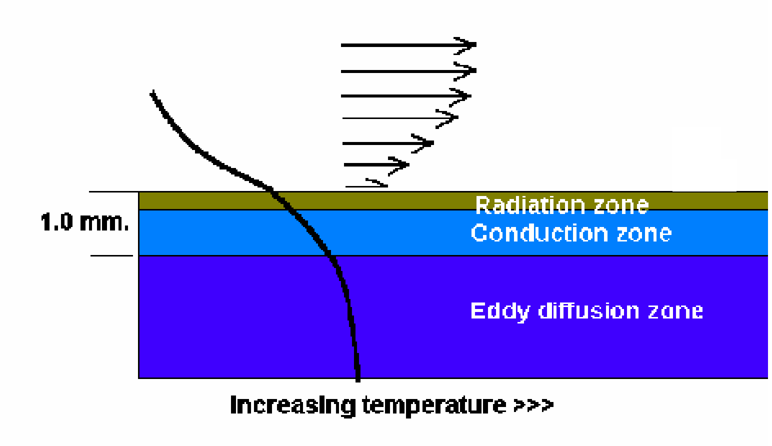
From Ward, B. and P. J. Minnett, 2001. An autonomous profiler for near surface temperature measurements. *Gas Transfer at Water Surfaces.* M. A. Donelan, W.M. Drennan, E.S. Saltzmann and R. Wanninkhof (Eds.) *American Geophysical Union Monograph 127.* 167 - 172.

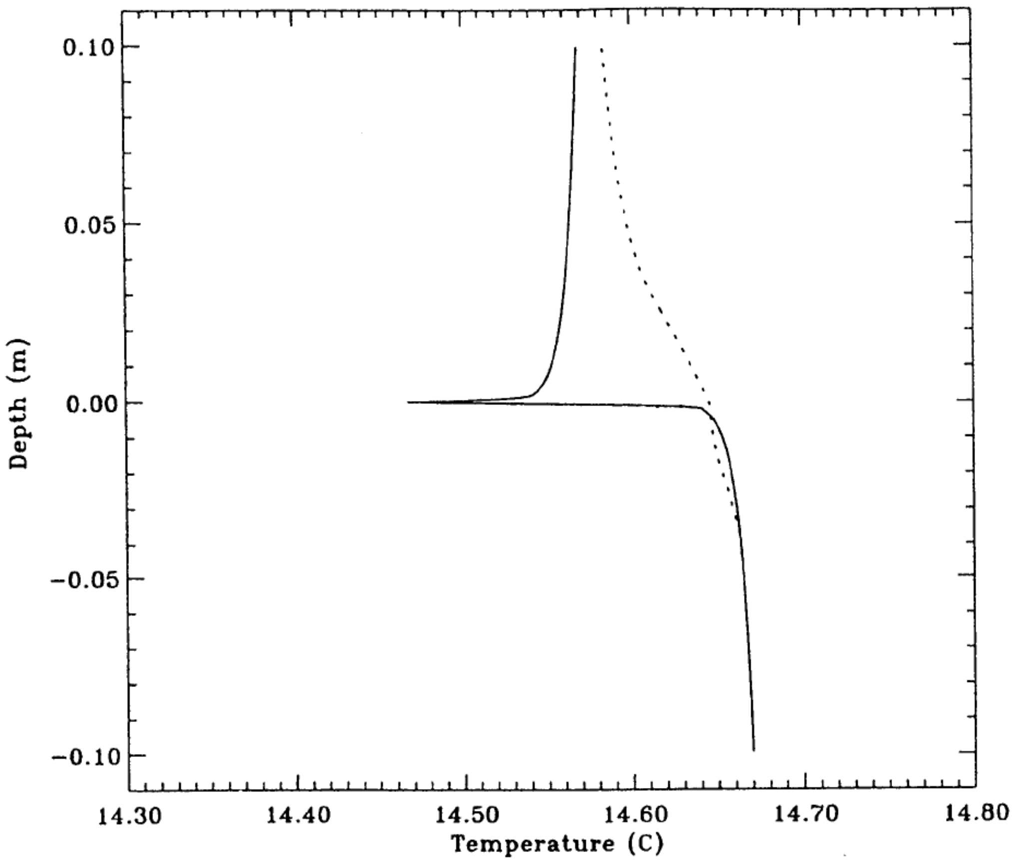
Conceptual picture:



Conceptual structure of the air-water interface (after McAllister, 1969).

Conceptual picture (revised):





Effect of infrared radiation sink at the interface (see Eifler and Donlon, 2001).

SST validation

- Sources of uncertainties in SST are
  - a) instrumental imperfections
  - b) imperfect correction for the effects of intervening atmosphere
- Primary validation must be radiometric – skin SSTs; M-AERI & filter radiometers.
- Use more numerous buoys to ‘fill in parameter space’ of atmospheric and oceanic variability.

Marine-Atmospheric Emitted Radiance Interferometer (M-AERI)

Specifications

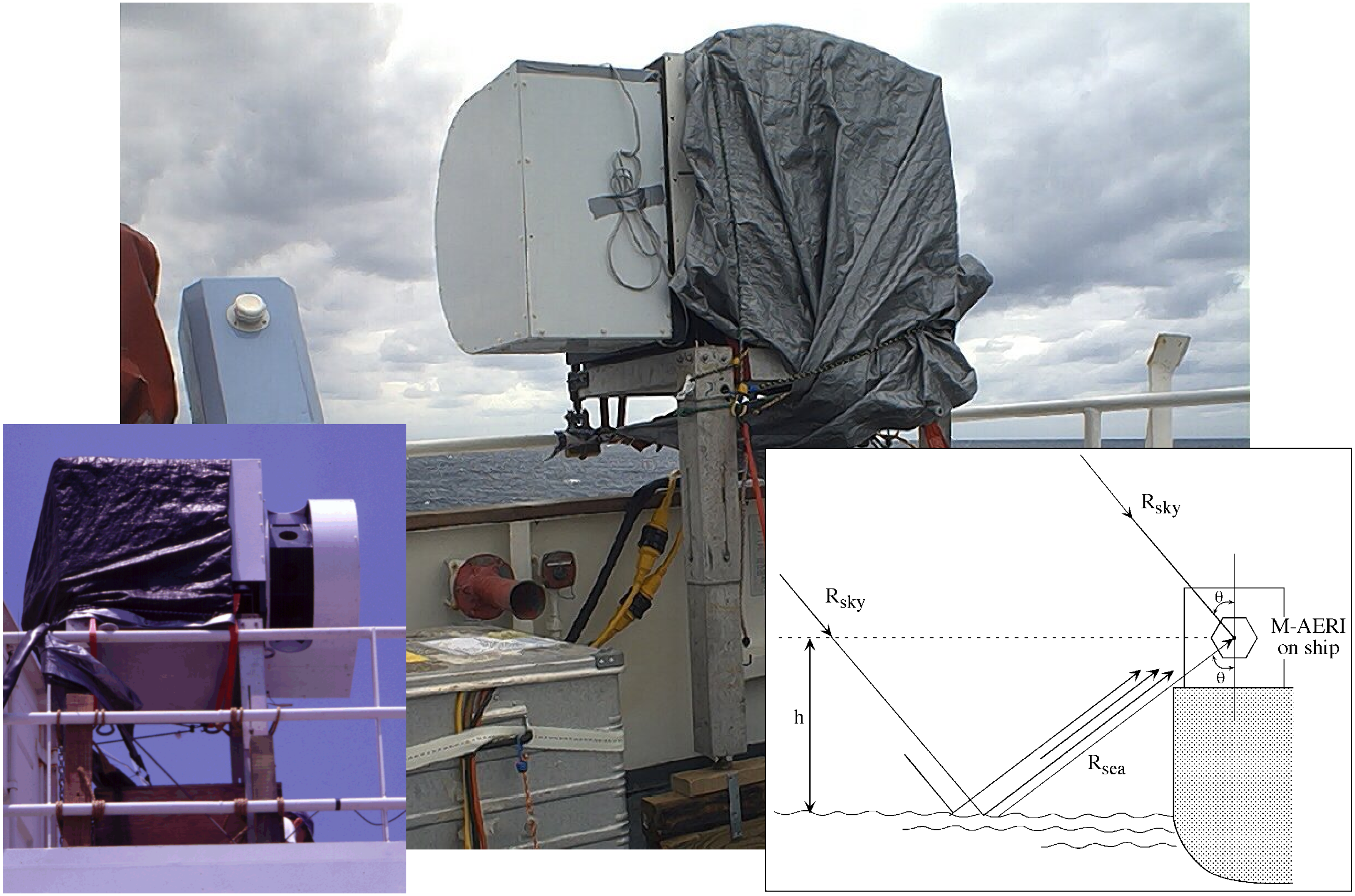
Spectral interval	~3 to ~18μm
Spectral resolution	0.5 cm $^{-1}$
Interferogram rate	1Hz
Aperture	2.5 cm
Detectors	InSb, HgCdTe
Detector temperature	78^{o}K
Calibration	Two black-body cavities
SST retrieval uncertainty	<< 0.1K (absolute)

Laboratory tests of M-AERI accuracy

Target Temp.	LW (980-985 cm^{-1})	SW (2510-2515 cm^{-1})
20^{o}C	+0.013 K	+0.010 K
30^{o}C	-0.024 K	-0.030 K
60^{o}C	-0.122 K	-0.086 K

The mean discrepancies in the M-AERI 02 measurements of the NIST water bath blackbody calibration target in two spectral intervals where the atmosphere absorption and emission are low. Discrepancies are M-AERI minus NIST temperatures.

M-AERI on USCGC *Polar Star*, March 2000



Radiometers for VIIRS Validation

- No single group has enough radiometers to provide an authoritative validation.

- Can measurements from radiometers of different design be combined into a single validation data set?

Miami-2001 Radiometer Intercalibration Workshop.

To cross-calibrate and compare infrared radiometers used in the validation of the SSTs derived from earth observation satellites. These aims included an assessment of the relative performance of each instrument as well as ensuring that surface measurements used in satellite product validation are traceable to SI standard units.

Participants

Dr. Ali Abtahi	NASA Jet Propulsion Laboratory, Pasadena, CA, USA
Dr. Ian Barton	CSIRO Marine Research, Hobart, Australia
Dr. Jim Butler	NASA GSFC, Greenbelt, MD, USA
Dr. Craig Donlon	EEC Joint Research Centre, Ispra, Italy
Dr. Marianne Edwards	Leicester University, UK
Ms. Ruth Fogelberg	Applied Physics Laboratory, U. Washington, Seattle, WA,USA
Ms. Jenny Hanafin	RSMAS-MPO, University of Miami, FL, USA
Dr. Simon Hook	NASA Jet Propulsion Laboratory, Pasadena, Ca., USA
Dr. Andy Jessup	Applied Physics Laboratory, U. Washington, Seattle, WA, USA
Dr. Carol Johnson	NIST, Gaithersburg, MD, USA
Ms. Erica Key	RSMAS-MPO, University of Miami, FL, USA
Ms. Trina Lichtendorf	Applied Physics Laboratory, U. Washington, Seattle, WA, USA
Mr. Kevin Maillet	RSMAS-MPO, University of Miami, FL, USA
Dr. Peter Minnett	RSMAS-MPO, University of Miami, FL, USA
Dr. Tim Nightingale	Rutherford Appleton Laboratory, Chilton, UK.
Dr. Mike Reynolds	Brookhaven National Laboratory, USA
Dr. Joe Rice	NIST, Gaithersburg, MD,USA
Dr. Goshka Szczodrak	RSMAS-MPO, University of Miami, FL, USA
Dr. Brian Ward	NOAA, AOML, Miami, FL, USA
Dr. Gary Wick	NOAA, ETL, Boulder, CO., USA

Instruments

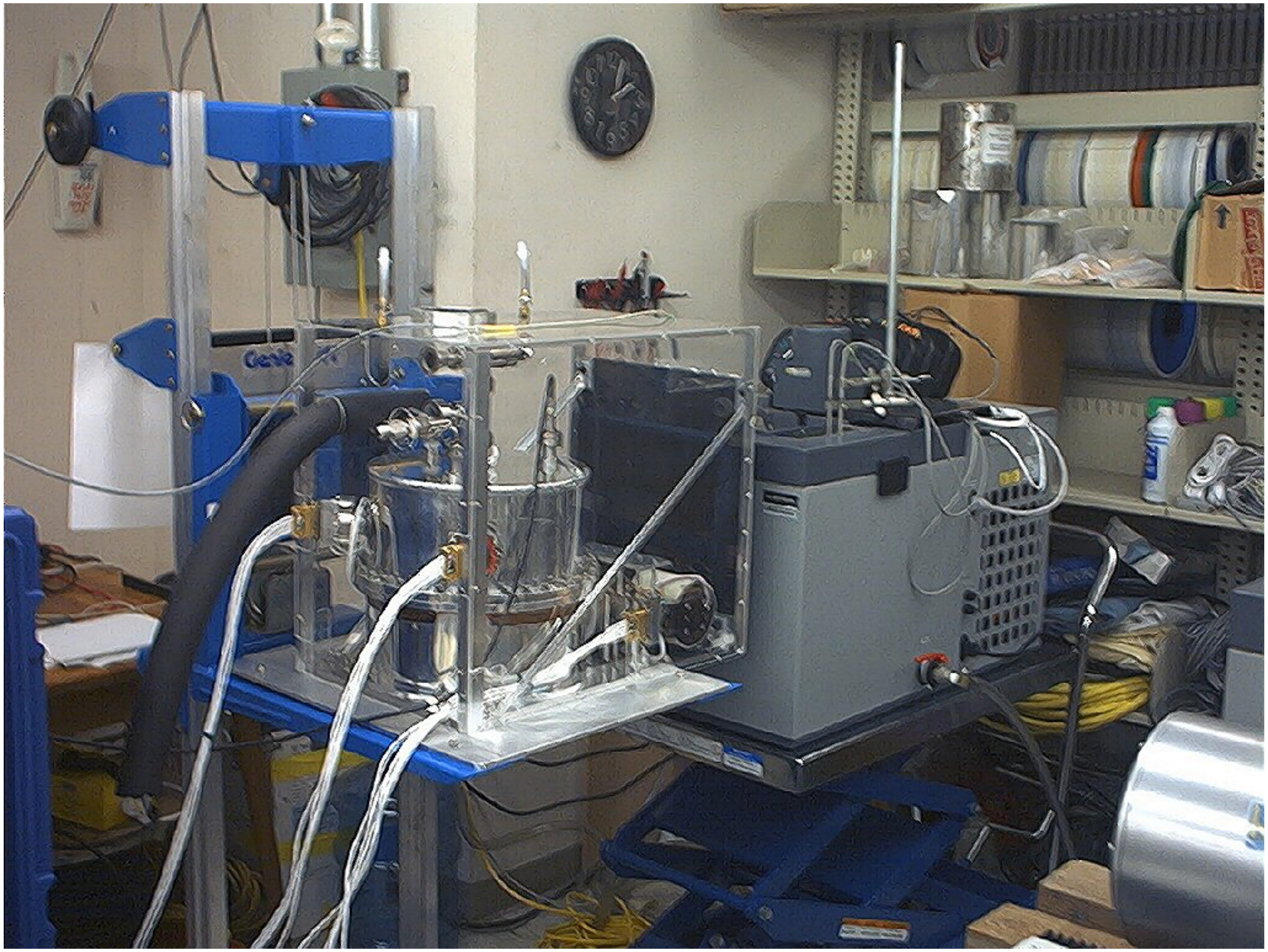
Infrared radiometers that participated in the campaign

Instrument	Institution	Lab.	Sea	P.I.
EOS TXR (Transfer radiometer)	NIST, USA	Yes	No	J. Rice
M-AERI	RSMAS, U. Miami.	No	Yes	P. Minnett
SISTeR	RAL,UK.	Yes	Yes	T. Nightingale
DAR011	CSIRO, Australia.	Yes	Yes	I. Barton
CIRIMS	APL, U. Washington.	No	Yes	A. Jessup
ISAR-5	JRC, EEC.	Yes	Yes	C. Donlon
Nulling radiometers	NASA JPL	Yes	Yes	S. Hook
Tasco (off-the-shelf)	CSIRO, Australia	Yes	Yes	I. Barton

Black bodies used for laboratory calibration.

Instrument	Institution	P.I.
NIST-Certified & Designed Black Body Target	RSMAS, U. Miami	P. Minnett
NIST Standard Black Body Target	NIST, USA	C. Johnston
CASOTS black body	JRC, EEC	C. Donlon
Hart Scientific Portable Black Body Target	APL, U. Washington	A. Jessup
JPL Black Body Calibrator	NASA-JPL	S. Hook

The NIST EOS TXR



CSIRO DAR011 at the RSMAS WB-BB target

Miami-2001Radiometer Intercalibration Workshop.

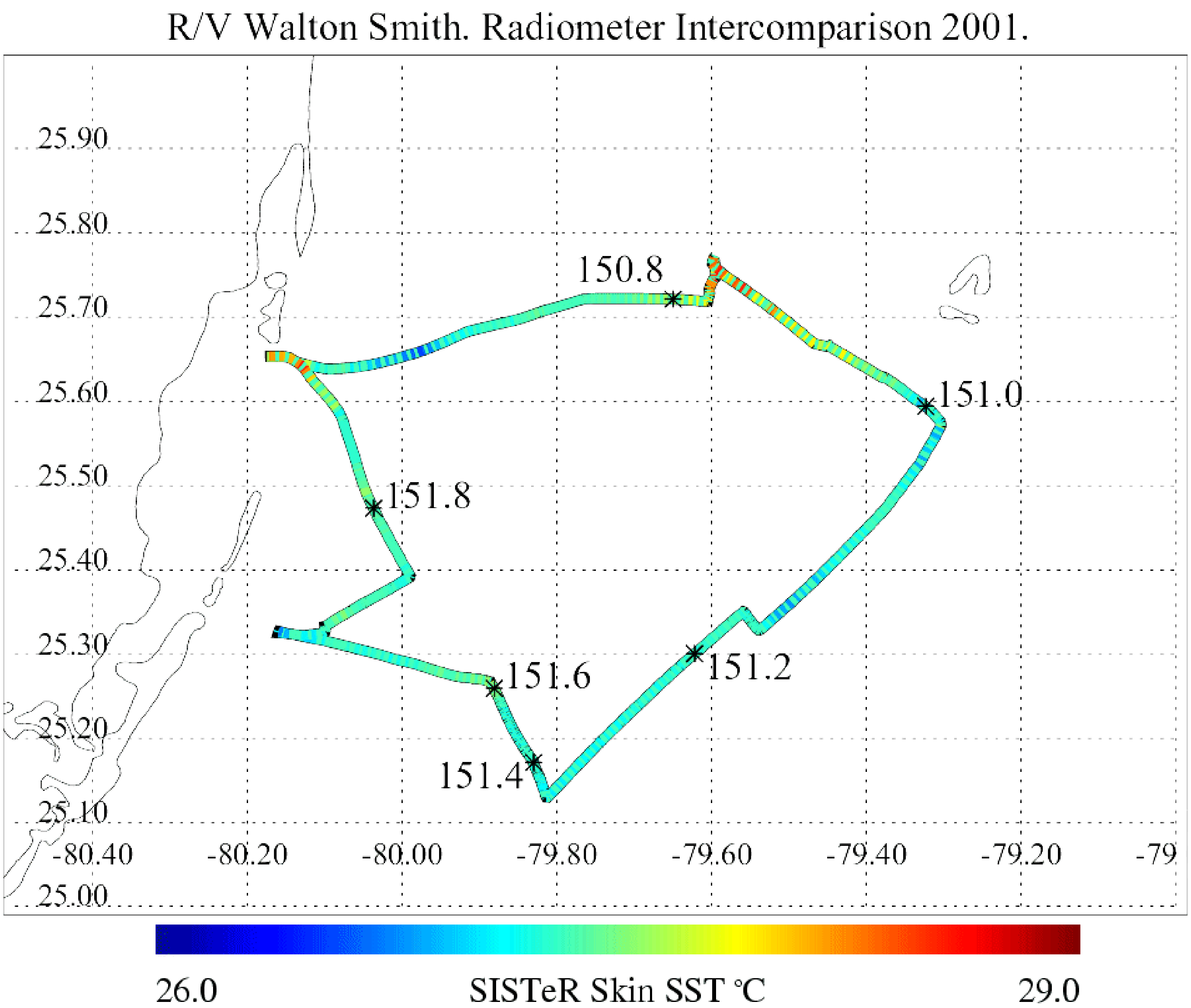
Following the radiometer calibration, intercomparison, and testing under field conditions, the international community should have increased confidence in the results to be provided for validation of satellite-derived SSTs from the participating instruments.

On the R/V *F.G. Walton-Smith*

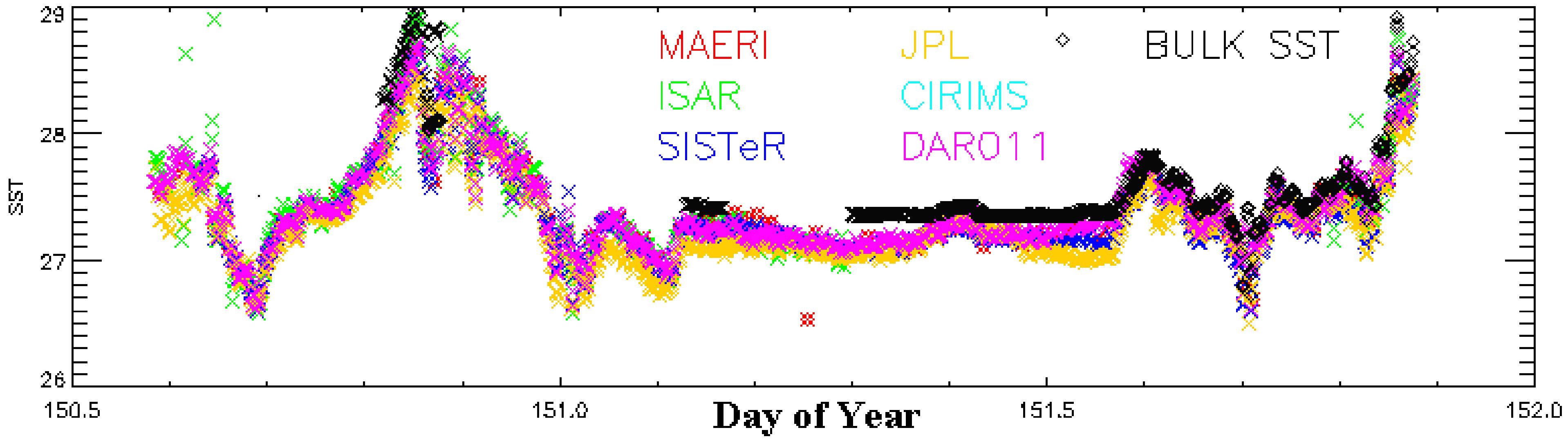
The SST radiometers

The radiometers

Cruise track



Time series of measurements



Results of at-sea comparisons

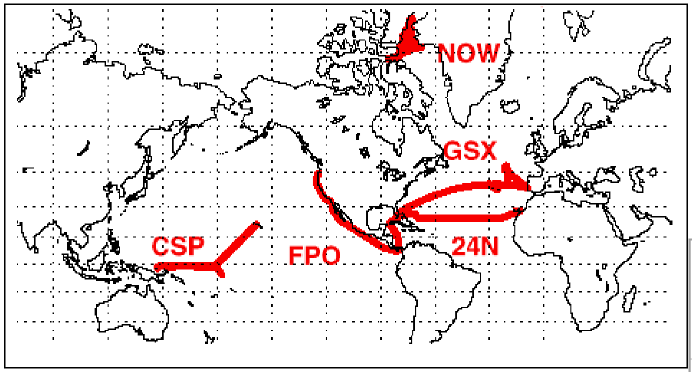
Means and standard deviations of the estimated skin SST differences between pairs of radiometers for the entire cruise period, and for each half of the cruise.

Time	150.50 to 152.00			150.50 to 151.25			151.25 to 152.00		
Radiometer Pair	Mean (K)	Std.Dev (K)	No.	Mean (K)	Std.Dev (K)	No.	Mean (K)	Std.Dev (K)	No.
MAE-ISA	0.002	0.135	80	0.005	0.135	69	–0.015	0.135	11
MAE-SIS	0.046	0.066	144	0.046	0.066	74	0.045	0.068	70
MAE-JPL	0.108	0.115	148	0.154	0.112	77	0.058	0.096	71
MAE-DAR	-0.008	0.076	149	0.022	0.071	78	–0.041	0.067	71
ISA-SIS	0.038	0.101	79	0.030	0.101	67	0.085	0.093	12
ISA-JPL	0.123	0.137	80	0.123	0.136	69	0.122	0.152	11
ISA-DAR	0.007	0.114	80	0.019	0.112	69	–0.064	0.107	11
SIS-JPL	0.053	0.099	144	0.092	0.102	74	0.012	0.078	70
SIS-DAR	-0.053	0.074	144	–0.019	0.054	74	–0.088	0.076	70
JPL-DAR	-0.112	0.113	149	–0.122	0.121	78	–0.100	0.103	71

Radiometric data for satellite SST validation

- Skin SST is source of signal detected by infrared satellite radiometers.
- Use of radiometers for validation is comparing “like with like.”
- For example, satellite-derived SST accuracy determined with buoy data includes near surface SST variability.
- Buoy SST validation of AVHRR & MODIS gives rms uncertainty of ~0.5K.

AVHRR-MAERI SST validation experience



Using skin temperatures reduces the uncertainties by about a factor of two.

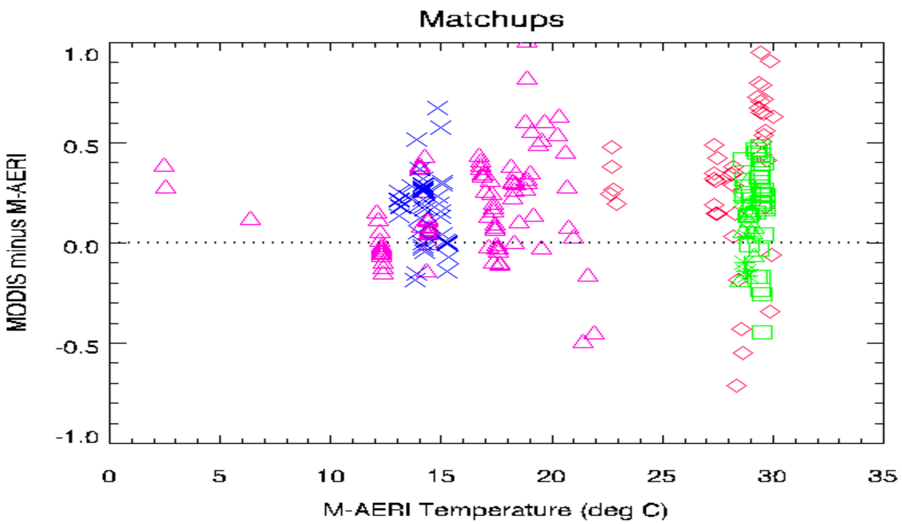
See Kearns *et al*, 2000, ***Bull. Am. Met. Soc***., **81**, 1525-1536

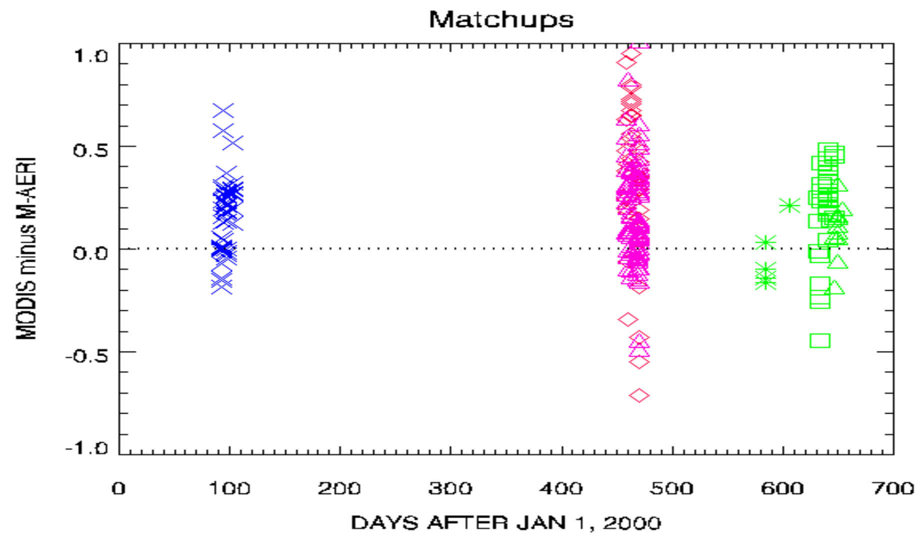
M-AERI validation of Pathfinder SSTs

Cruise Name	N	Mean K	St. Dev. K
CSP 1996	**23**	**0.16**	**0.20**
24N 1998	**16**	**0.03**	**0.18**
GASEX 1998	**168**	**-0.01**	**0.25**
FPO 1998	**47**	**0.27**	**0.40**
NOW 1998 (Arctic)	**176**	**0.24**	**0.44**
Total, all data	**430**	**0.13**	**0.37**
Total, excluding NOW data	254	0.06	0.29

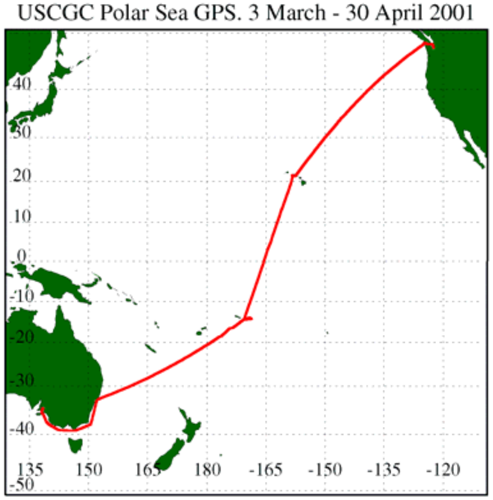
MODIS-M-AERI Matchups

Blue = Mediterranean – April 2000; Red =Pacific – March, April 2001; Pink = Pacific – March, April 2001; Green = Atlantic - Explorer of the Seas.





USCGC Polar Sea GPS. 3 March - 30 April 2001

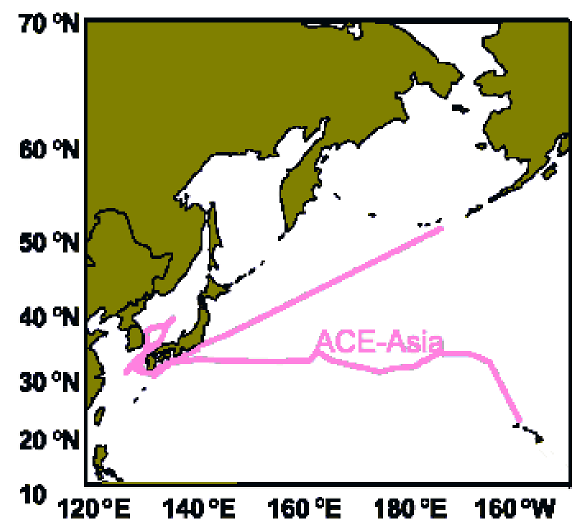


<u>All data</u>

M = 0.20K
std= 0.26K
N = 242

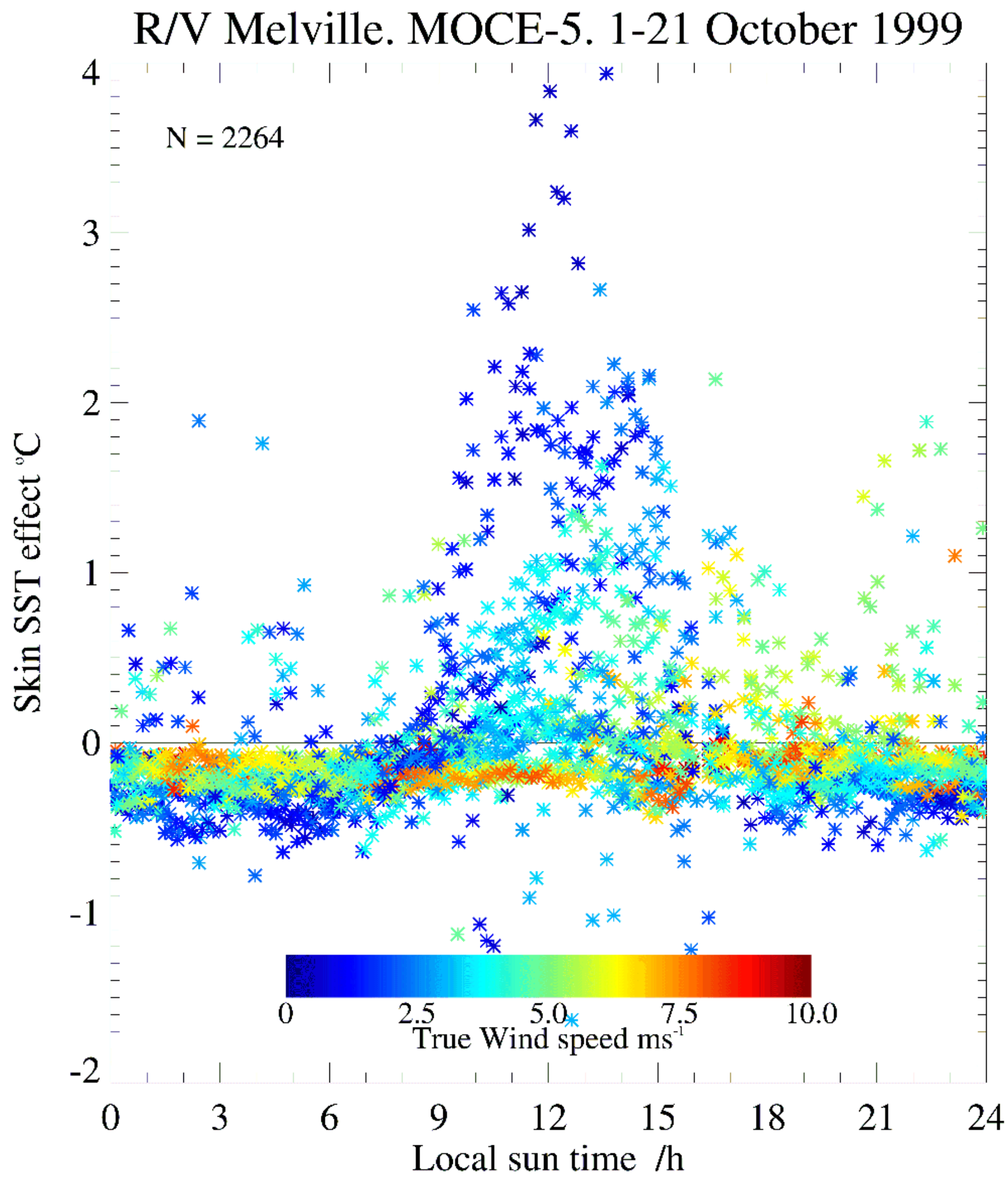
<u>Explorer of the Seas</u>

M = 0.15K
std= 0.21K
N = 50

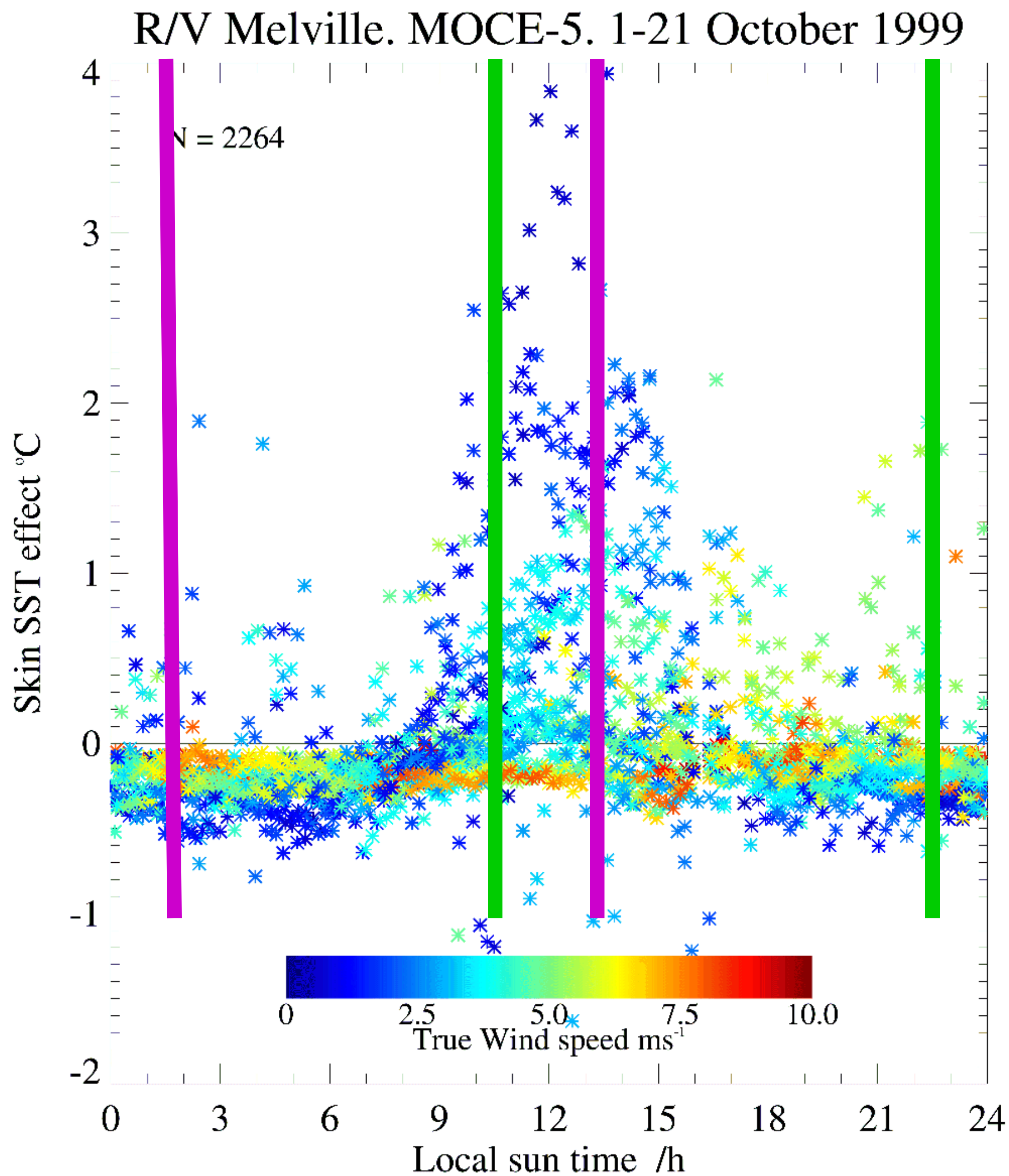


Wind speed dependence of diurnal & skin effects

Note: effects of diurnal thermocline effects at low winds

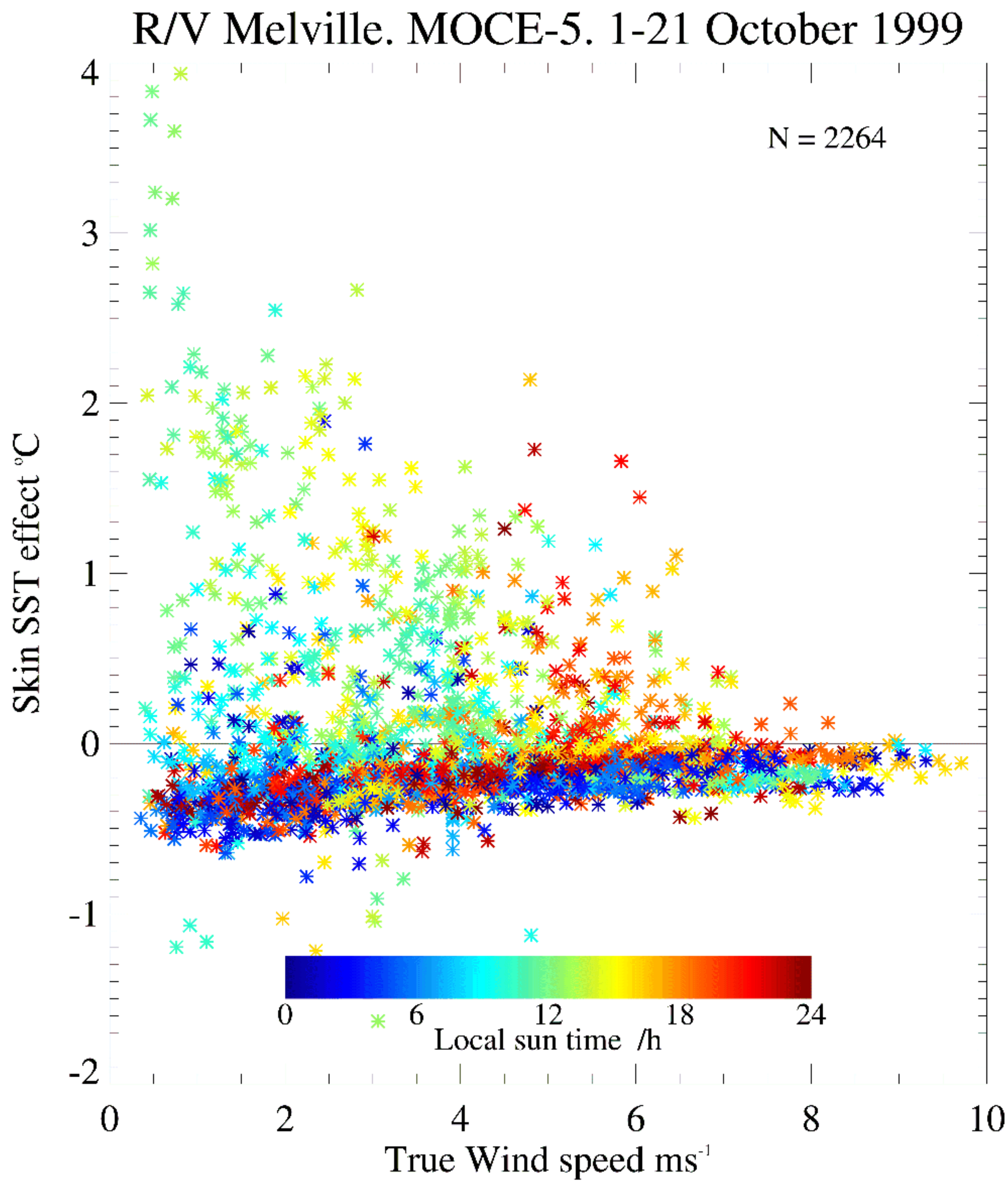


Wind speed dependence of diurnal & skin effects



Terra and Aqua overpass times.

Wind speed dependence of the skin effect



Note collapse of envelope at moderate to high wind speeds.

Universal behavior of the skin effect?

Similar behavior of the skin effect – different instruments, different investigators, different ships, different oceans.

From Donlon, C. J., P. J. Minnett, C. Gentemann, T. J. Nightingale, I. J. Barton, B. Ward and J. Murray (2002). "Towards improved validation of satellite sea surface skin temperature measurements for climate research." <u>J. Climate</u> **15**: 353-369.

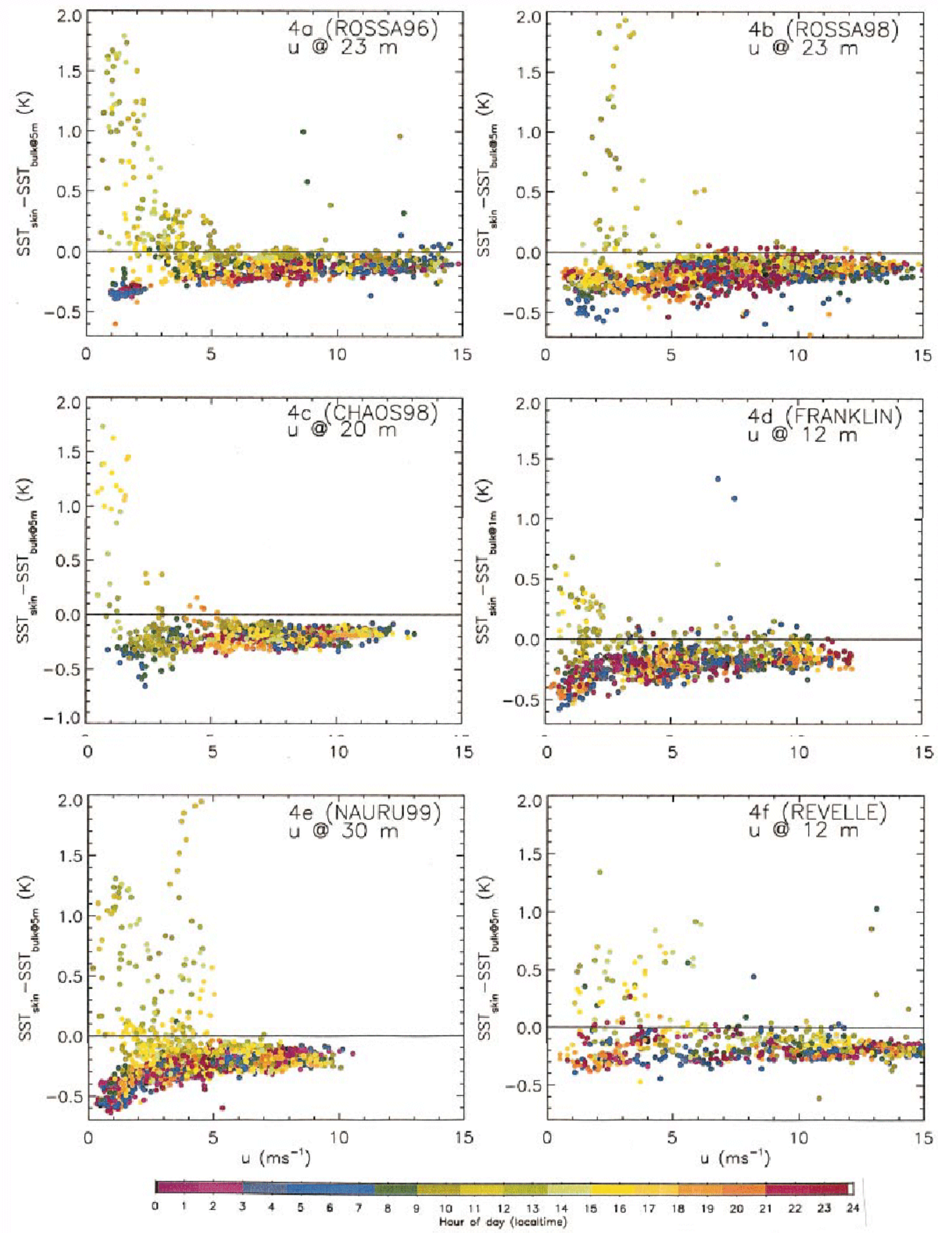


FIG. 4. The ΔT_{depth} as a function of wind speed. Each point is a 10-min mean measurement and has been colored according to the local time of day at the mean acquisition time (a) ROSSA 1996 $\Delta T_{depth\ 5\ m}$ as a function of wind speed at 23 m. (b) ROSSA 1998 $\Delta T_{depth\ 5\ m}$ as a function of wind speed at 23 m. (c) CHAOS 1998 $\Delta T_{depth\ 5\ m}$ as a function of wind speed at 20 m. (d) R/V *Franklin* $\Delta T_{depth\ 1\ m}$ as a function of wind speed at 12 m. (e) Nauru 99 $\Delta T_{depth\ 5\ m}$ as a function of wind speed at 30 m. (f) R/V *John-Revelle* $\Delta T_{depth\ 5\ m}$as a function of wind speed at 12 m.

Night-time behavior of the skin effect

362 JOURNAL OF CLIMATE VOLUME 15

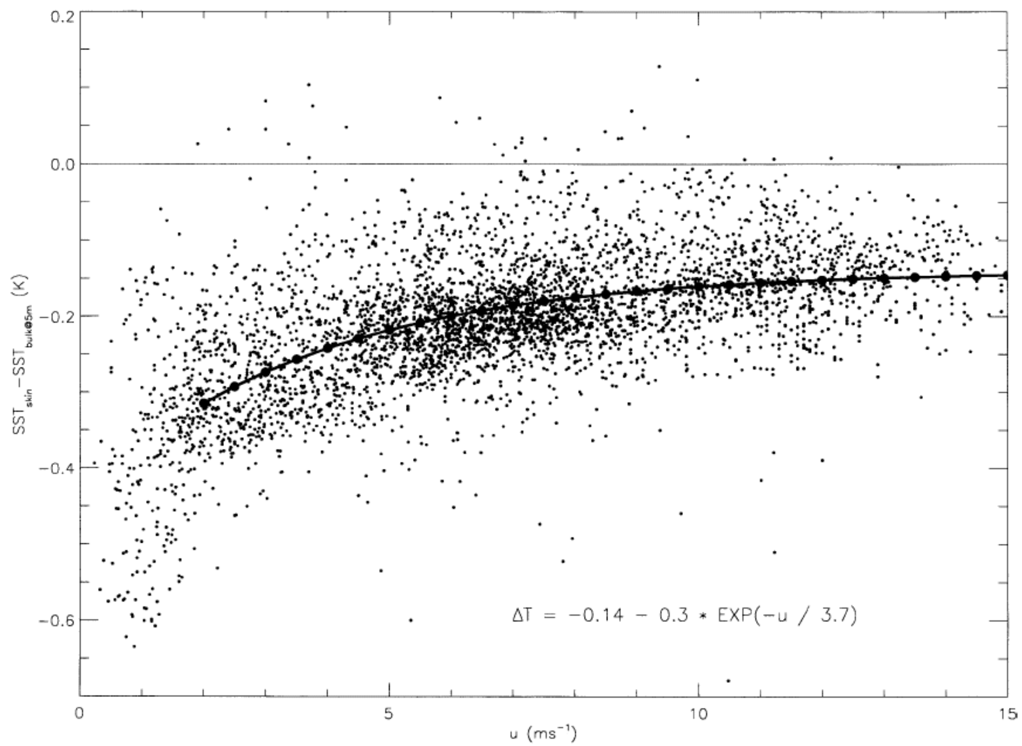


FIG. 5. All nighttime only $\Delta T_{\text{depth 5 m}}$ data (as shown in Fig. 4) plotted as a function of wind speed.

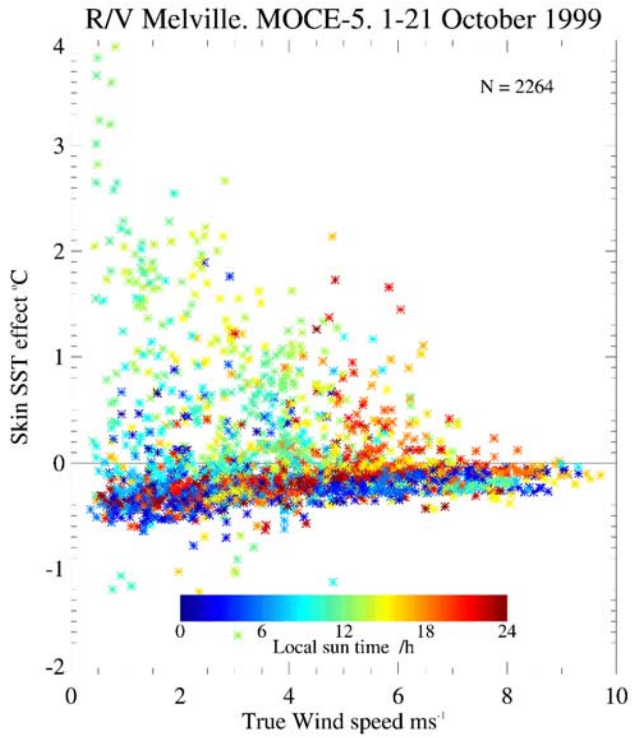
$$\Delta T = -0.14 - 0.3 * \exp(-U/3.7)$$

From Donlon, C. J., P. J. Minnett, C. Gentemann, T. J. Nightingale, I. J. Barton, B. Ward and J. Murray (2002). "Towards improved validation of satellite sea surface skin temperature measurements for climate research." J. Climate **15**: 353-369.

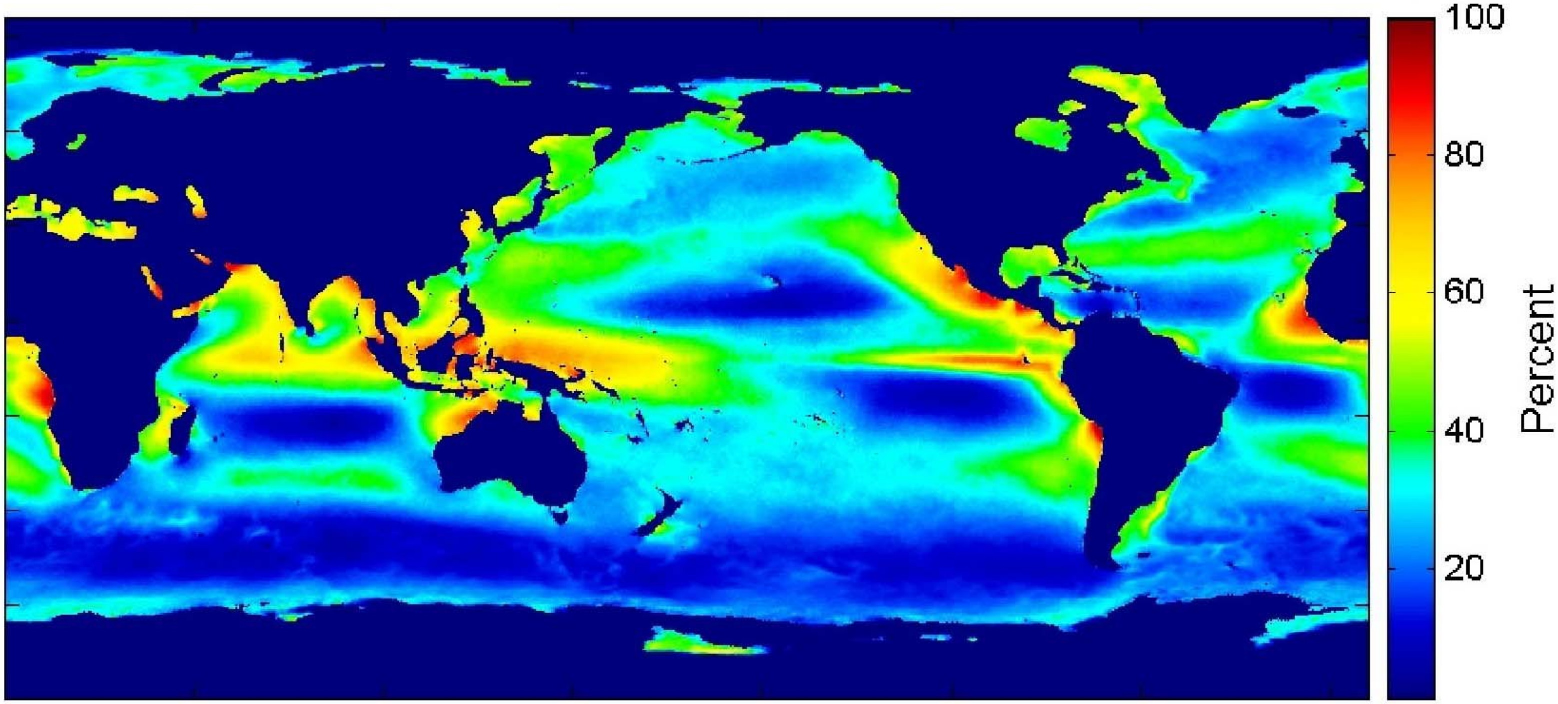
Wind speed criterion for SST validation

For winds > ~$6ms^{-1}$, relationship between skin and bulk SSTs becomes quite well behaved, at the level of ~0.1K. In these conditions daytime bulk SST may be used to validate satellite-derived SSTs.

See Donlon, C. J., P. J. Minnett, C. Gentemann, T. J Nightingale, I. J. Barton, B. Ward and J. Murray, 2002. Towards improved validation of satellite sea surface skin temperature measurements for climate research. ***J. Climate***. **15**: 353-369.



Distribution of wind speed <6ms^{-1}



Buoy data can be used, with caution, in blue areas

From Donlon, C. J., P. J. Minnett, C. Gentemann, T. J Nightingale, I. J. Barton, B. Ward and J. Murray, 2001. Towards improved validation of satellite sea surface skin temperature measurements for climate research. ***J. Climate***. **15**: 353-369.

Terra MODIS Issues

- Infrared radiometry at this level of accuracy is hard to do.
- Instrument is very complex.
- Multiple detectors result in ‘striping’.
- Surface coating on mirror causes a strong angular dependence of reflectivity in the infrared ($\lambda \geq \sim 8\mu m$)
- Two sides of scan mirror have different properties – leads to striping in groups of ten scan lines.
- Changing between redundant electronics components in data stream changes character of signal.
- LSB of digitizer is noisy.
- Dynamic range of some SST bands is sub-optimal.
- Optical cross-talk is less of an issue for SST than for atmospheric sounding.

MODIS Experience (I)

- At launch algorithms may not necessarily work as well as expected.
- Fall-back algorithm can be derived from heritage instrument fields (provided that they are well validated). This has added advantage of providing continuity of product.
- It takes time to generate a sufficient body of independent ‘match-ups’ to validate the product and determine error characteristics.
- Good pre-launch characterization is vital to understanding instrument behavior, and to producing accurate data.

MODIS Experience (II)

- For *Terra* MODIS, IR measurements of inside of closed Earth View door have been very valuable: angular effects on mirror reflectivity & mirror sidedness.
- Optical and electronic stability of instrument on orbit is important. Reconfigurations can compromise empirical corrections.
- Minimization of optical and electronic cross-talk is important.
- Teasing apart instrumental and environmental contributions to the signal can be a challenge.

Conclusions

- Using skin SSTs to validate satellite-derived SSTs gives a better estimate of uncertainties in the satellite-derived fields.
- Thermal skin effect much less variable than previously thought, and relationship at night or in moderate to high winds is good.
- Diurnal effects are a challenge.
- *Terra* MODIS has provided some valuable lessons.

Miami-2001Radiometer Intercalibration Workshop.

Acknowledge funding from

- NOAA-NESDIS
- ESA
- Eumetsat
- Participant’s home institutes and funding agencies

Acknowledgements

- Captains, officers and crew of the many ships that have hosted M-AERI.
- Many colleagues at RSMAS, MCST, GSFC, SSEC, UK Met Office, and elsewhere.
- Funding from NASA, NSF & DOE.

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Infrared Penetration Depths

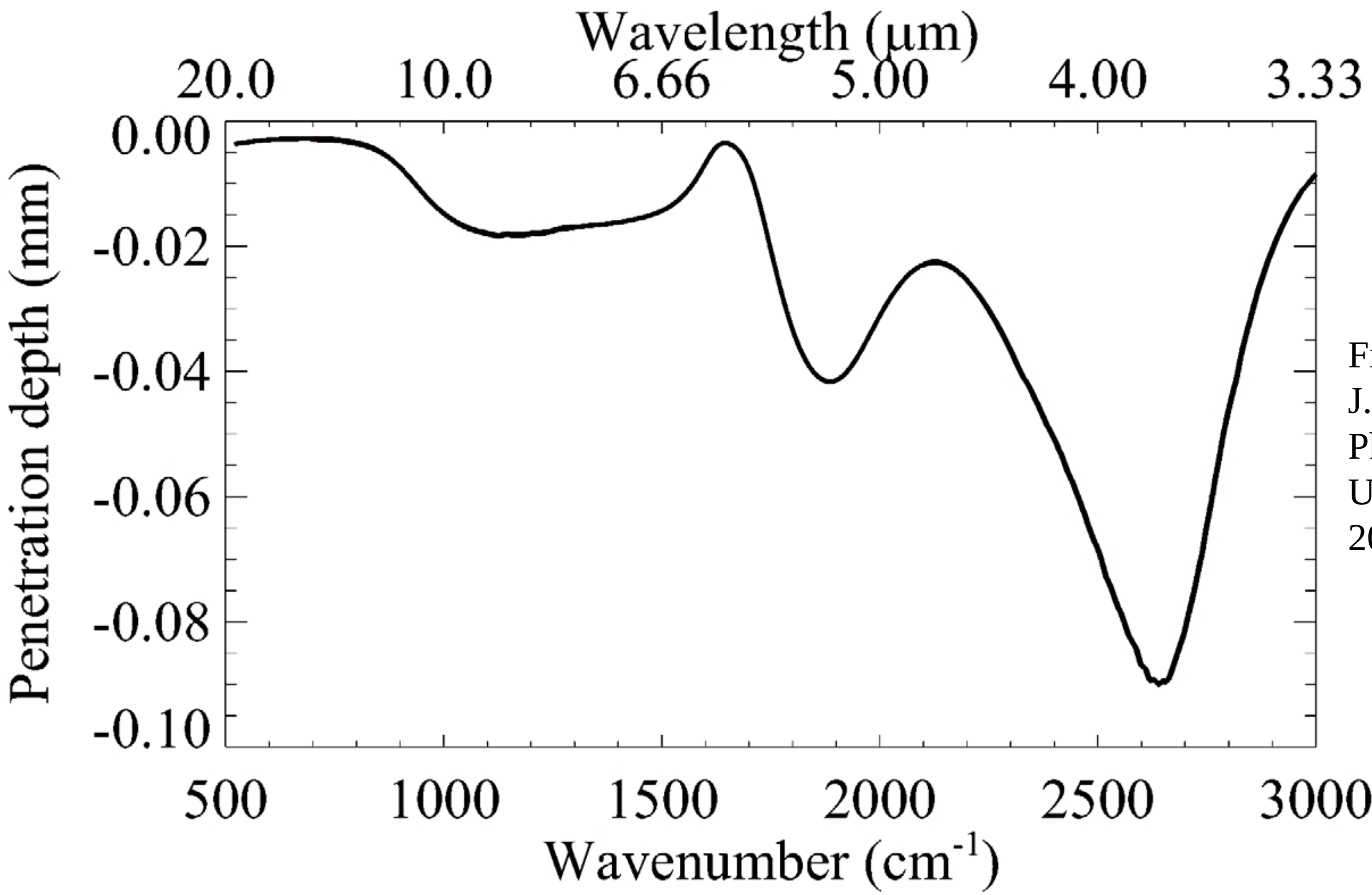
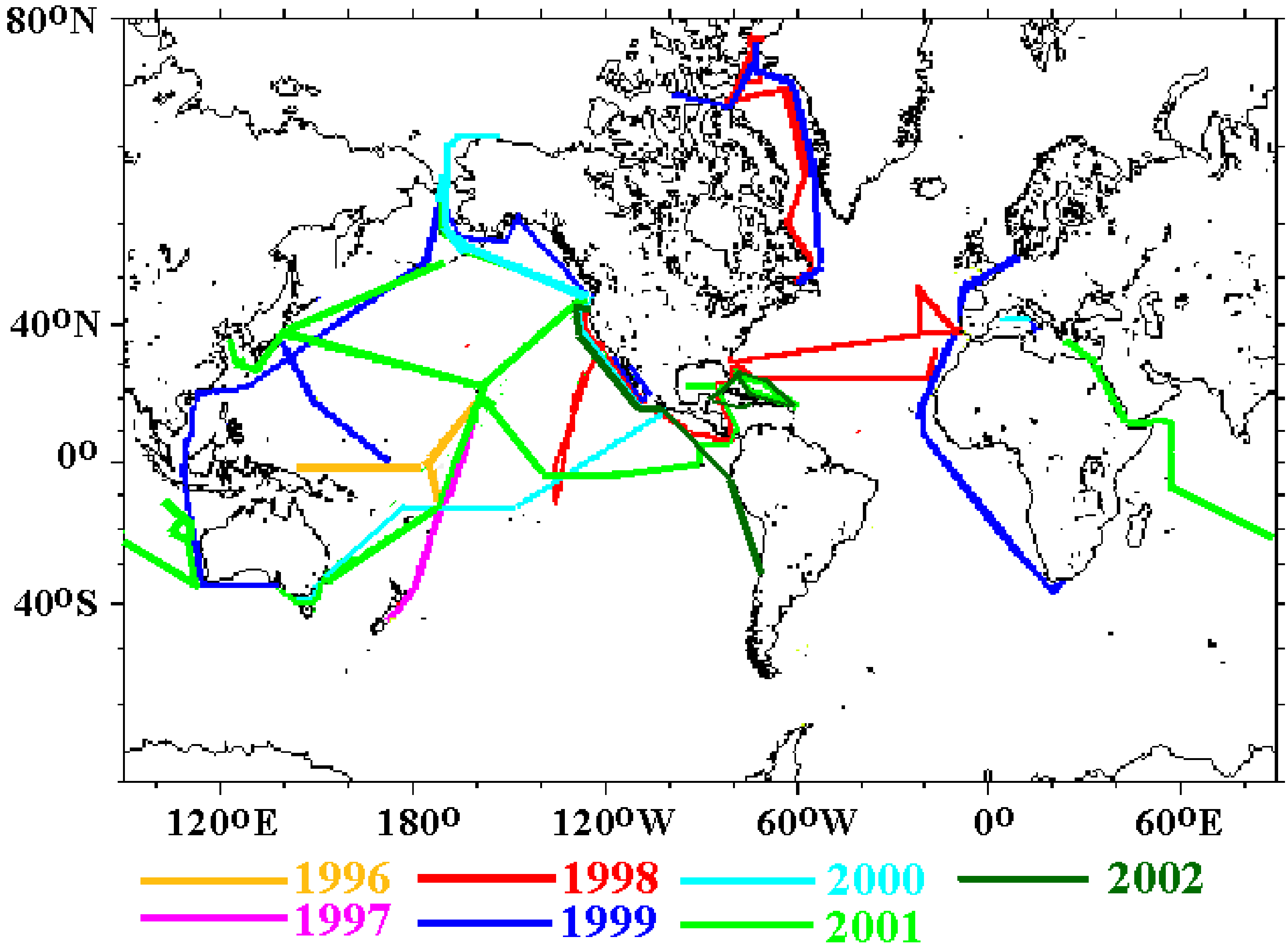


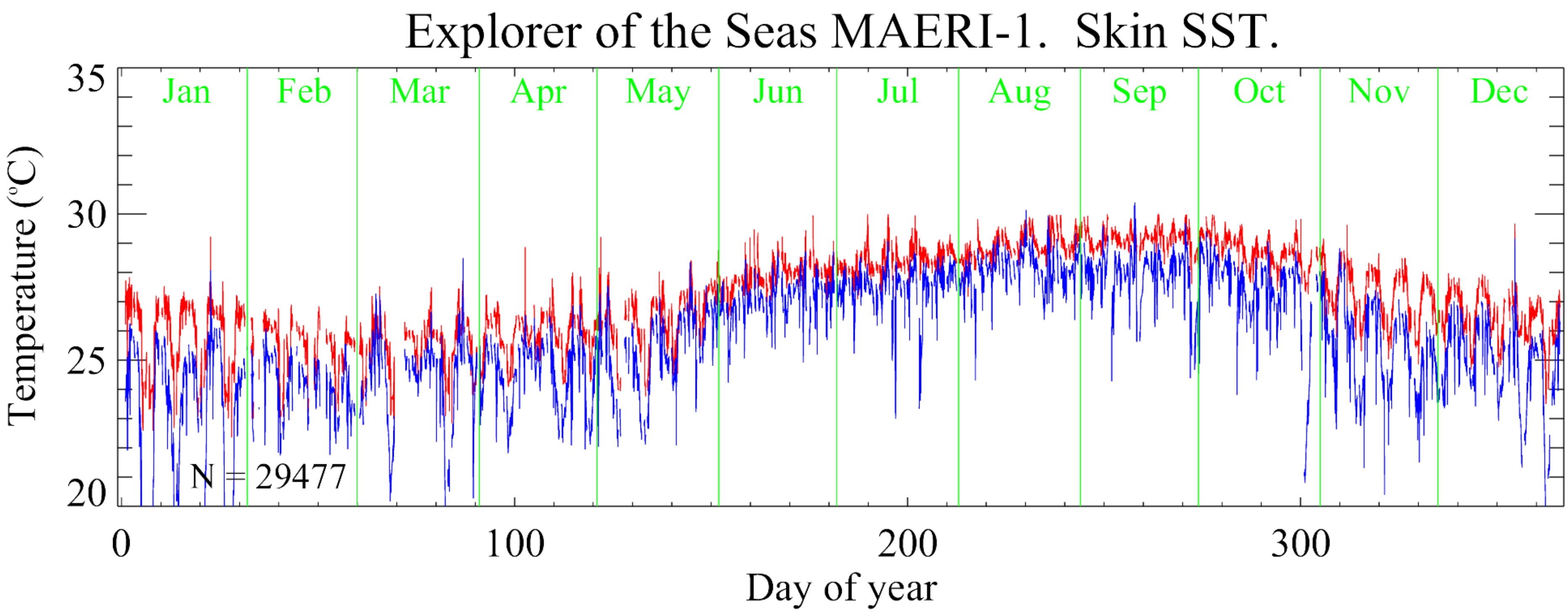
Figure from J. A. Hanafin, PhD Thesis. U. Miami 2002.

Given there is a temperature gradient through the skin layer, the value of the 'skin temperature' measured by a radiometer will be wavelength dependent.

M-AERI cruises



M-AERI data from *Explorer of the Seas*



Time-series of M-AERI measurements on *Explorer of the Seas*

The *Explorer of the Seas* is a Royal Caribbean Cruise Liner, operating a bi-weekly schedule out of Miami. It is outfitted as an oceanographic and atmospheric research vessel, very suitable for satellite validation. For more details see http://www.rsmas.miami.edu/rccl/

UK Met Office Approach: Skin – Bulk Relationship

Following slides from:

Parametrisations of the skin effect and implications for retrieval of SST from (A)ATSR

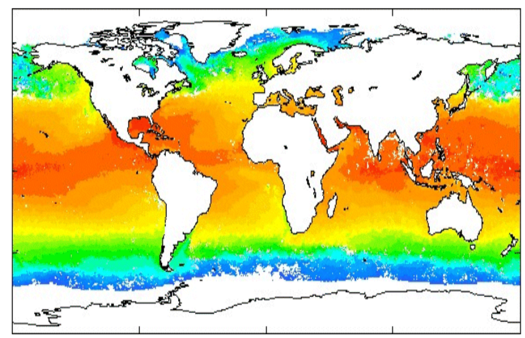
Lisa Horrocks

Brett Candy
Roger Saunders
Anne O'Carroll

Tim Nightingale (RAL)
Andy Harris (NOAA)

Project aim

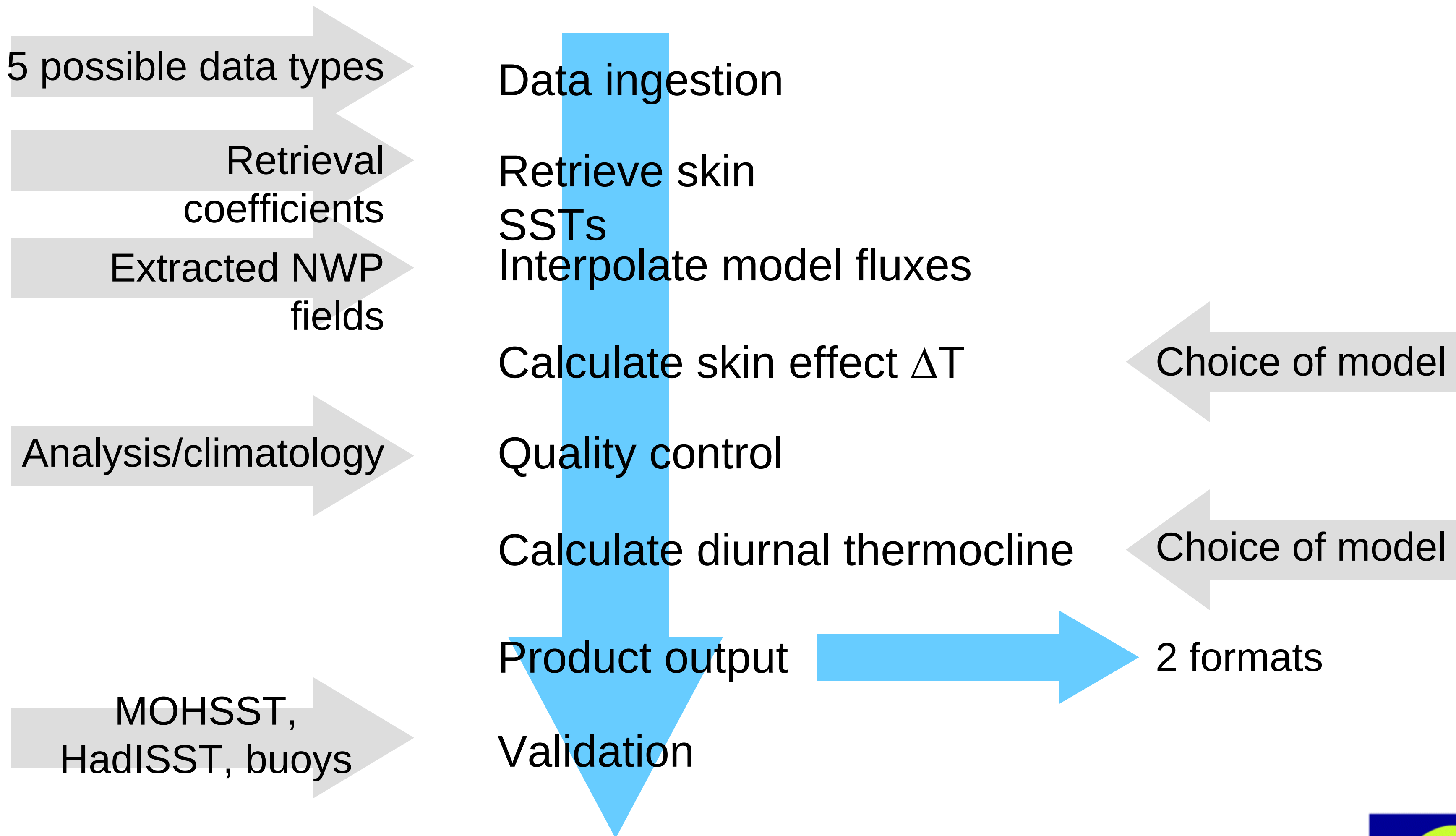
- Use (A)ATSR data to improve and augment SST analyses for climate studies



  - Deliver high quality SST product to Hadley Centre
  - Reconcile discrepancies between in situ measurements and the satellite data product

Met Office

UK – Met Office Processing software



Fairall simulations

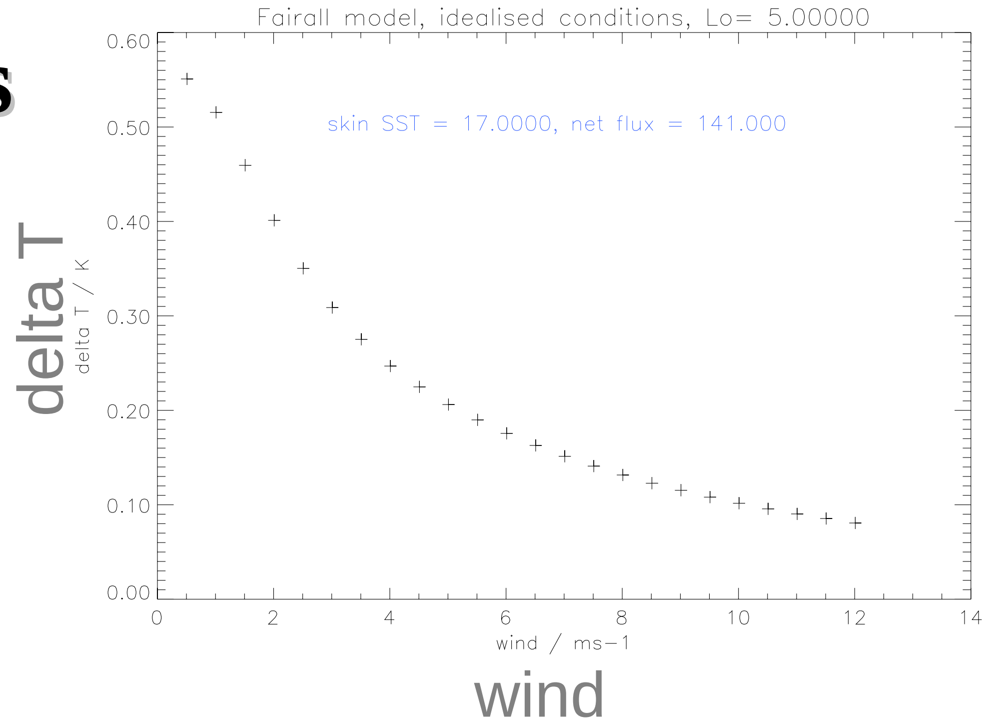
- Saunders (1967) scheme for forced convection

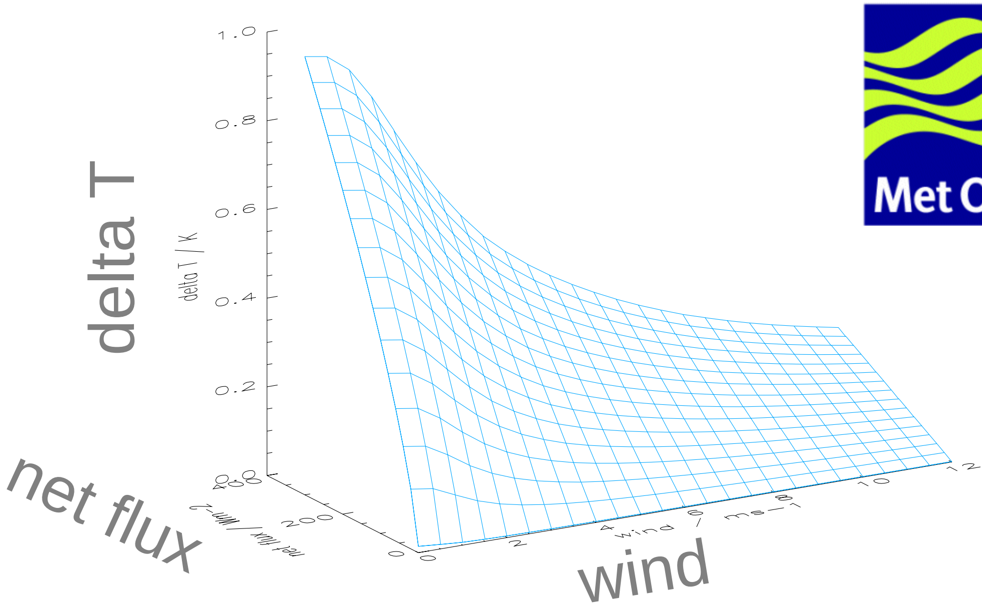
$$\Delta T = \lambda \frac{Q\nu}{ku_*}$$

- To include free convection, redefine λ to make it buoyancy-dependent:

$$\lambda = \lambda_o \frac{1}{\left[1 + \left(\frac{\lambda_o^4 A^3 Q g \alpha \rho c_p \nu^3}{u_*^4 k^2}\right)^{3/4}\right]^{1/3}}$$

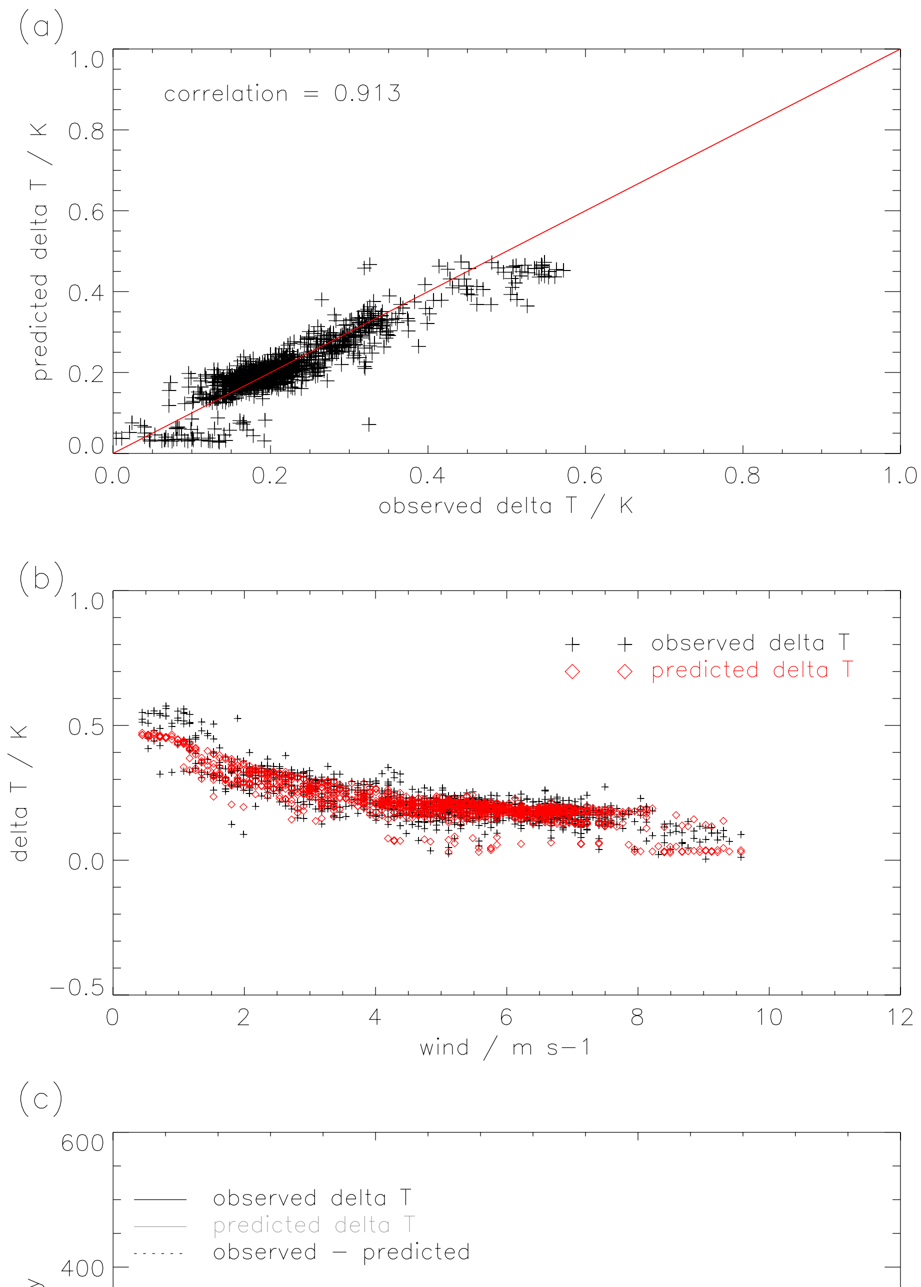
- At high wind speeds, $\lambda \mapsto \lambda_o$





Met Office

Fairall predicted vs observed



- Use in situ met data
- Trend with wind speed correctly predicted
- Use λ_o value of 4.6

Model comparisons

Table 2: Summary of the skin effect model predictions.

		Mean ΔT / K	$\sigma (\Delta T)$ / K	Mean δT_{o-p} / K	$\sigma (\delta T_{o-p})$ / K	Correlation
Obs	Observed	0.216	0.084			
	Exponential	0.216	0.072	< 0.001	0.043	0.86
Fairall	FA	0.212	0.074	0.027	0.045	0.92
S&S	SS	0.204	0.038	0.012	0.080	0.34
Wick	WI	0.178	0.036	0.038	0.073	0.51
	FA (NWP)	0.211	0.062	0.005	0.050	0.80

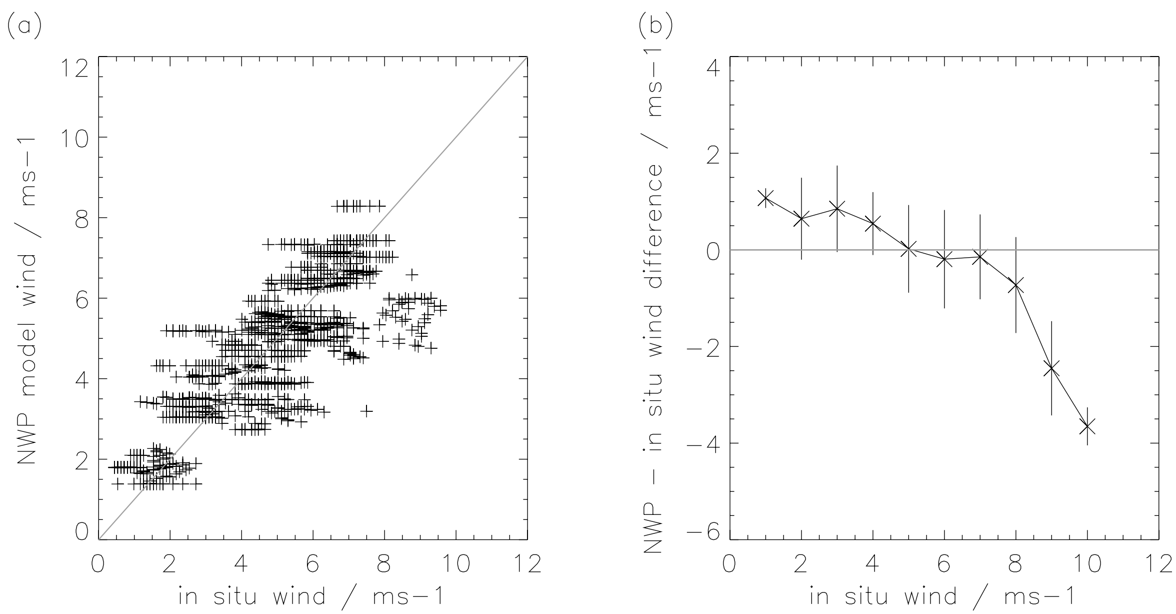
Notes: Mean ΔT represents bulk minus skin temperature difference. Mean δT_{o-p} represents observed minus predicted ΔT difference. The correlation value was calculated as the simple product-moment correlation coefficient between observed and predicted ΔT.

match

minimise

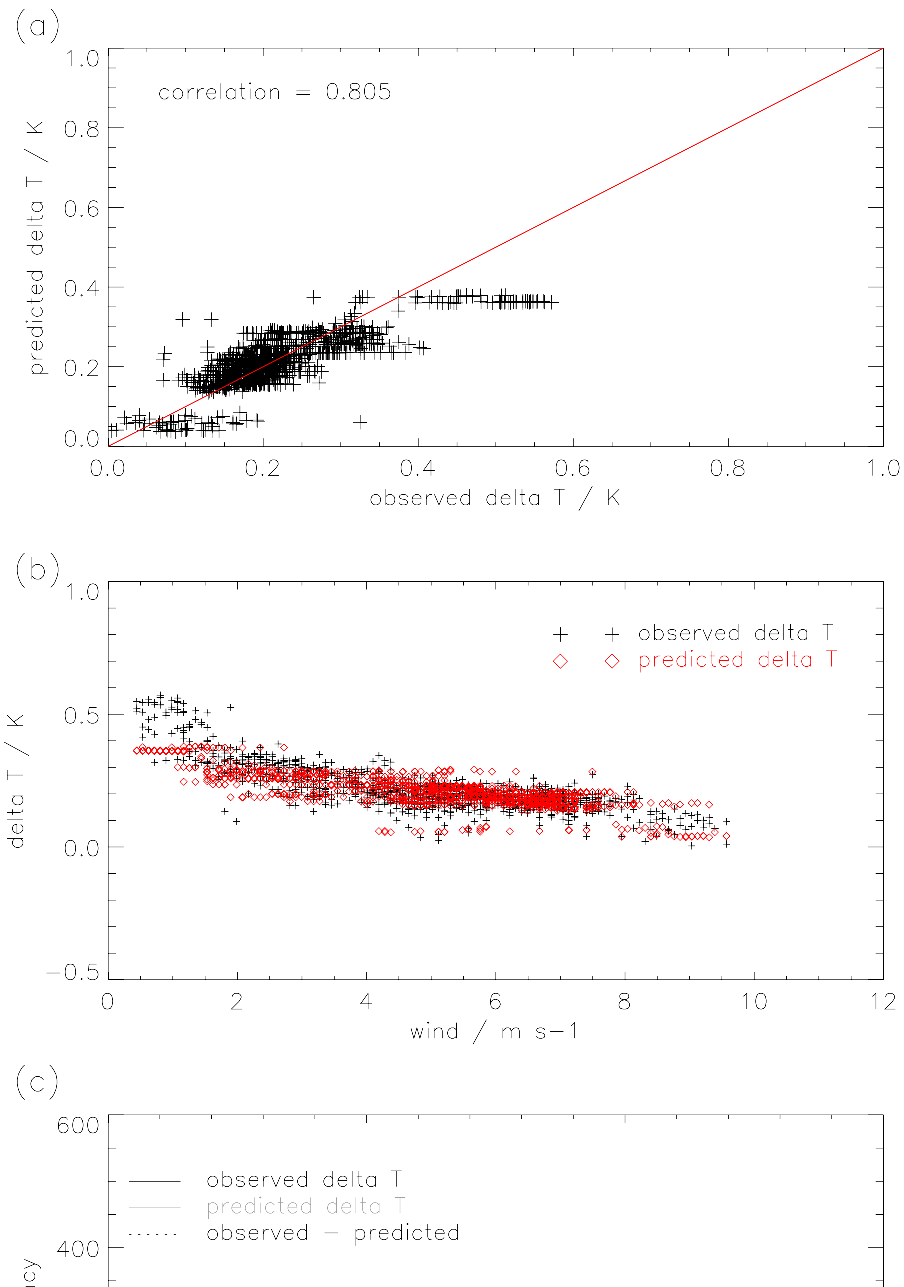
maximise

NWP fluxes



- Fluxes are 6-hr averages
- Errors at extremes of range: e.g. wind
- May cause systematic errors in delta T
  - Implications for climate analysis

Fairall predicted vs observed (2)



- Use NWP flux data
- Use λ_o value of 4.6
  - as derived before
- Need a systematic correction of -0.04 K
  - from flux errors

$$\Delta T_{obs} = \Delta T_{model} - 0.04$$

Summary :

- Met O study so far limited to night time data.
- Skin effect ‘in hand’
- Concerned about simulating diurnal heating, as forcing (from NWP model) is available only at 6hr intervals……..